TRANSACTIONS.

CYLINDRICAL WHEELS AND FLAT TOPPED RAILS FOR RAILWAYS.

By D. J. WHITTEMORE, Past President Am. Soc. C. E.

" Fool," said my Muse to me, "look into thy heart and write."
—Sir Philip Sidney.

The Scrap Heap—that inarticulate witness of our blunders, and the sepulcher of our blasted hopes ; the best, but most humiliating legacy we are forced to leave to our successors—has always, to me, been brim-full of instruction.—THE AUTHOR.

Present practice imposes from two to three times the weight on railway wheels that was customary a few years ago. This taxes not only the permanent way rolling-stock and engine-power to the utmost, but also the genius, and, I may say, the courage of the engineer, in his endeavor to secure safety under the most trying conditions.

Economy of train service has become so important, that it is safe to say there will be no return to lighter loads unless it shall be thoroughly demonstrated that both safety and economy require it. Instead of this being the result, I apprehend that still further increased capacity will be demanded, until the loads carried will be limited on our standard gauge only by the size of cars that can pass over the line with sta-

bility and at such high velocity as may hereafter be demonstrated as practicable.

Car wheels and rails to the value of nearly a billion dollars pass into the scrap heap every few years on this Continent alone. It is my belief that they would give a much longer service if they were designed and constructed according to established and well known laws of mechanics. In this we have been too long the slaves of precedent. In making this broad statement I do not wish to imply that through forty years of professional service I have been without guilt in the matter of which this paper treats ; or that the persistence in errors is confined to American engineers; for the particular errors to which I allude probably exist in a higher degree outside our own country.

If it is true that the tendency is to heavier loads, and that the scrap heap claims wheels and rails which should be capable of longer service —and I think there is no one who will dispute it—then there is hardly any one problem that deserves the earnest consideration of our members and of this Society more than the question of the relation of wheels and rails to each other. The disastrous effects produced by the monstrous loads per wheel must surely impress us with the necessity of an early solution of the problem they create. It would be interesting if we could determine what should be the tonnage service of rails. The report of the Committee on the relation of wheel and rail to each other* indicates that this is approximately 10 000 000 tons† to $\frac{84}{100}$ pound per yard of tangent rail abraded. If the section of rail referred to approximates the one shown in the report, this means that the rail should be worn down about one millimeter. Couard, of France, estimates that one millimeter of wear corresponds to 16 800 000 tons, and that a rail can be made that can be worn down ten millimeters. Lanino calculates the life service at 150 000 000 ; and Funk, of Germany, 125 000 000; and the latter also states that a good rail may be worn down over one-half inch.

Many of our rails go into the scrap heap with only $\frac{1}{16}$ of an inch abraded. Undoubtedly this is partly due to poor material in many instances, but in the large sense, I contend, it is due to faulty design of rail.

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* Preliminary Report of the Committee on the Proper Relation to each other of the Sections of Railway Wheels and Rails. Transactions, Vol. XIX, July, 1888.

† The ton referred to in this paper is 2 000 pounds.

It is equally interesting and pertinent to inquire into the wear of wheels reduced to a tonnage basis. Of the ordinary cast iron car wheel we have an abundance of statistical information as to its mileage ; but I have not at hand the requisite data to permit me to determine the ton service with that approximate degree of accuracy desired. Of engine drivers I gather something from an interesting paper read before the Institution of Civil Engineers a few years ago by William Stroudly, of the London, Brighton and South Coast Railway of England—that tires of locomotive drivers, 78 inches in diameter, carrying a weight of 7.84 net tons, wear down $\frac{1}{8}$ of an inch for each 28 000 miles of travel. This would indicate that the service of this $\frac{1}{8}$ inch was 56 770 000 tons, or for a wear of one millimeter, 18 000 000 tons.

Through the kindness of our Member, Mr. J. N. Barr, Superintendent of Motive Power of the Chicago, Milwaukee and St. Paul Railway Company, I am able to present the following table, on page 136, showing tire wear of forty locomotives that had made an aggregate of over 6 000 000 miles—equivalent to turning one wheel 27 000 000 miles, and carrying a weight of from 14 000 to 16 000 pounds ; from which we deduce the result that a tonnage of 41 000 000 causes a wear of $\frac{1}{8}$ of an inch in the tread of the tire.

Through the courtesy of Mr. G. W. Rhodes, Superintendent of Motive Power of the Chicago, Burlington and Quincy Railway, I give tire wear of several standard locomotives in use on his line, in which there is shown a great difference in service in the use of tires of different thickness, and in both cases much lower service than is shown by Mr. Barr's report :

TABLE No. 1.

WEAR OF TIRE, CHICAGO, BURLINGTON AND QUINCY RAILWAY.

CLASS OF ENGINE.	Size.	Number of Drivers.	Total Weight on Drivers.	Miles run to $\frac{1}{8}$ Wear, 3-inch Tire.	Miles run to $\frac{1}{8}$ Wear, 4-inch Tire.
Switch engine, no truck.........	15 x 22–44	4	50 150	6 045	3 711
Switch engine, no truck.........	16 x 22–44	4	59 238	4 675	3 387
Road engine, forward truck......	16 x 24–53	4	44 367	7 168	4 937
Road engine, forward truck......	17 x 24–57	4	48 960	8 903	7 119

Reduced to ton service for $\frac{1}{8}$-inch wear of tire, the approximate average is :

For 3-inch tire..............................31 380 000
And for 4-inch tire..........................20 674 000

TABLE No. 2.

WEAR OF DRIVING WHEEL TIRE, CHICAGO, MILWAUKEE AND ST. PAUL RAILWAY.

Class of Engine.	Average diameter of tires.	Number of driving wheels.	Total weight on drivers in pounds.	Number of sets.	Number of runs.	Total wear in 32ds of an inch.	Total miles run.	Average miles run to ⅛ inch tire wear.	Tons service to each ⅛ inch of tire wear.	Tons service for one millimeter of tire wear.
Freight.										
17-inch Rhode Island........	62 inch.	4	55 450	5	19	193	995 555	20 633	46 512 691	
17 " "	62 "	4	55 450	5	12	173	699 040	16 163	36 435 149	
17 " "	62 "	4	55 450	5	17	235	893 320	15 205	34 276 470	
Passenger.										
18-inch Rhode Island........	62 "	4	58 500	5	19	201	978 506	19 473	46 893 785	
18 " "	62 "	6	58 500	5	14	159	744 453	18 728	44 633 699	
Ten-wheel freight............	62 "	6	81 000	10	23	334	1 458 332	17 465	38 348 471	
Standard 18-inch passenger..	68 "	4	64 400	5	5	49	373 819	30 475	72 758 595	
Average, excluding last....									41 042 414	12 935 760

The only explanation I can offer for the superior service shown by the 3-inch tire over that of the 4-inch is, that the material in the last must have been inferior in quality.

It will be seen by this table that the tire of the larger diameter gives the best service, as should be expected.

As you are aware, drivers are turned in sets to suit the greatest wear of any one wheel of its set, or rather to the spot of greatest wear of the most worn wheel ; hence this exhibit does not, even approximately, indicate the loss of metal due to abrasion ; but I give the information for what it is worth.

Making any reasonable allowance for this loss of metal by turning, let us see what is the tonnage service of steel-tired 33-inch car wheels under passenger cars of known weight and load, and where the only unknown element of wear enters to modify our conclusions, to wit, wear of brake shoes ; and again I am indebted to Mr. Barr for this information :

Coach No. 235, Chicago, Milwaukee and St. Paul Railway, weighing 61 500 pounds; passenger load, 4 500 pounds; total, 66 000 pounds; load per 33-inch wheel, 5 500 pounds—ran 95 110 miles, and suffered an average loss of $\frac{762}{1000}$ of one inch in circumference of wheel. Having the wear as measured on circumference of wheel, the weight in pounds carried by same, and the miles run, the following formula will give closely the tonnage service for each $\frac{1}{8}$ inch tread of 33-inch wheel worn down:

$$\frac{6 \text{ x weight on wheel in pounds x miles run}}{25 \text{ x circumference wear in inches}} = \text{Tons service}$$

for $\frac{1}{8}$-inch direct wear in thickness of tire.

In the case above cited the tonnage service for $\frac{1}{8}$ inch wear was:

$$\frac{6 \text{ x } 5\,500 \text{ x } 95\,110}{25 \text{ x } .762} = 164\,757\,428.$$

In further testimony, I offer the following table of average circumference wear of 33-inch steel tired car wheels of the passenger equipment of the Chicago, Milwaukee and St. Paul Railway, given by Mr. Barr, from which I deduce from the formula stated the tonnage service for wear down of tread for $\frac{1}{8}$ of an inch as shown. The average circumference wear is that of two wheels on the same axle:

TABLE No. 3.

WEAR OF STEEL TIRED WHEELS, 33-INCH DIAMETER, CHICAGO, MILWAUKEE AND ST. PAUL RAILWAY.

Weight of Car with Average load.	No. of Wheels to each.	Weight per Wheel. Pounds.	Miles Run.	Wear in inches, measured on Circumference.	Tons Service to ¼-inch wear down of Tread.
65 800	12	5 483	63 702	.600	139 711 226
67 700	12	5 642	77 534	.400	252 468 096
64 000	- 12	5 343	17 029	.150	145 305 051
80 400	12	6 700	59 493	.700	136 663 920
73 600	12	6 133	36 067	.250	212 350 954
77 500	12	6 458	41 583	.500	128 900 646
54 100	8	6 762	41 449	.625	107 661 256
59 500	8	7 438	80 444	.700	205 145 990
54 100	8	6 762	36 473	.500	118 382 604
64 200	12	5 350	64 872	.650	128 147 150
81 300	12	7 608	30 683	.375	149 399 208
81 300	12	7 608	76 470	1.275	109 543 923
47 000	8	5 875	72 795	.600	171 068 250
63 200	12	5 267	95 446	1.100	109 683 072
79 600	12	6 633	51 259	.550	148 364 049
64 000	12	5 333	47 132	.450	134 055 976
78 100	12	6 508	25 623	.200	200 105 380
59 800	12	4 893	69 653	.800	102 263 638
79 600	12	6 633	55 660	.350	253 160 763
77 900	12	6 492	54 083	.775	108 729 858
50 500	8	6 325	47 997	.700	104 084 922
65 200	12	5 433	60 884	.500	158 775 730
65 700	12	5 475	68 591	.850	106 080 675
				Average......	149 132 710

From the same source I gather the following data in reference to the performance of 42-inch steel tired wheels with cast iron hubs, and reducing to tonnage service for direct wear of ⅛ inch the formula,

$$\frac{\text{Mileage x weight in pounds on wheel}}{5\tfrac{3}{16} \text{ x circumference wear in inches}} = \text{Tons service,}$$

is used.*

Weight of Car and Average Load.	Number of Wheels.	Weight per Wheel.	Miles Run.	Wear in inches, Circumference Measurement.	Tons to ⅛ inch Wear.
82 000..........	12	6 833	105 439	.900	151 061 524
82 000..........	12	6 833	93 503	.600	204 027 012
				Average......	177 544 268

* Since this paper was dictated the author has devised the following convenient formula for determining tons service of wheels for a wear down of tread of ⅛ of an inch, applicable to wheels of any diameter, in which formula

a = reduced circumference of wheel through wear in inches.

b = miles run to produce such wear.

c = weight in pounds on wheel.

d = diameter of wheel in inches while in service.

$$\frac{7.92 \; b. \; c.}{a. \; d.} = \text{Tons service.}$$

Through the kindness of our Member, Theodore N. Ely, General Superintendent of Motive Power of the Pennsylvania Railway Company, the following table, showing the weights per wheel carried on that line, is compiled. The freight tariff of that company, however, permits 64 000 pounds paying load, where 60 000 is stated in this table.

TABLE No. 4.

PASSENGER EQUIPMENT CARS.

KIND OF CAR.	Weight, Pounds.	Load. Pounds.	No. of Wheels.	Weight on each Wheel.*
Passenger.....................................	50 000	7 830	8	6 902 pounds.
Baggage..	34 700	16 000	8	6 011 "
Express..	32 500	14 000	8	5 486 "
Postal	58 000	20 000	12	6 174 "
Combination	39 500	16 000	8	6 611 "
Emigrant......................................	36 500	7 830	8	5 867 "

Weight of passenger car axle............... 326 pounds.
    "   "   " wheel.............. 540   "

FREIGHT EQUIPMENT CARS.

KIND OF CAR.	Weight, Pounds.	Load. Pounds.	No. of Wheels.	Weight on each Wheel.†
Box car " Xc."............................	30 100	60 000	8	10 682 pounds.
Stock car " Kd."......	27 800	60 000	8	10 435 "
Coal car " Gd."..............................	23 500	60 000	8	9 797 "

Weight of freight car axle.................. 400 pounds.
Weight of freight car wheel................. 540   "

LOCOMOTIVES.

CLASS.	Diameter of Driving Wheels.	Diameter of Truck Wheels.	Weight on Drivers.	Weight on Truck.	Weight on each Driver.	Weight on each Truck Wheel.‡
A Passenger.........	68 inches.	33 inches.	64 000	29 500	16 000	7 375
N "	62 "	33 "	57 700	33 600	14 425	8 400
O "	62 "	33 "	58 300	33 600	14 575	8 400
P "	68 "	33 "	67 800	32 800	16 950	8 200
R Freight...	50 "	28 "	100 600	14 025	12 575	7 012
K Express passenger	78 "	33 "	64 900	31 800	16 225	7 950

*Weight on each wheel is exclusive of weight of wheel.
†Weight on each wheel is exclusive of weight of wheel. Weight of box and stock cars includes air brakes fixtures.
‡Weight on each wheel includes weight of wheel.

TENDERS.

KIND.	Weight. Pounds.	Load. Pounds.	No. of Wheels.	Weight on each Wheel.*
Passenger.....................................	29 300	35 250	8	7 528 pounds.
Freight..	29 000	40 300	8	8 127 "

When we make allowance for wear due to brake shoes and the flow of metal, the tonnage service for abrasion due to rail contact will be largely increased. How it is that there is such disparity between engine drivers and passenger wheel tonnage service will appear, if my premises are correct, further on.

In fact, there are so many varying and conflicting conditions, and so much data wanting, such as loss by corrosion, etc., that it seems about as impossible to determine a fair expression for abrasion due to rolling load alone, as to have the Missouri River act according to mathematical formulas. I submit that the facts presented indicate pretty clearly that failure does not result so much from abrasion as from some other cause.

To secure increased service of wheels and rails, the remedy proposed by the author is indicated by the caption of this paper, to wit, "Cylindrical Wheels on Flat Topped Rails." I do not wish it understood that I mean that the entire width of rail top should be flat, or that if made flat it could continue so for any great length of time. The difference in gauge between wheel flanges and rails permits a lateral movement of, say, $\frac{5}{8}$ of an inch, or more. Owing to difference of wear by reason of wheels running to or from flange, a curve characteristic of this wear is produced, and which will extend along the line of bearing from the flange contact, a distance equal to at least one-half of this lateral movement of wheels on rails, making the origin of the curve about $\frac{3}{4}$ of an inch from the side of the rail head. This will hold true also for both top corners of the rail. The balance of the rail top, I contend, should be flat.

When the subject of rails was under discussion at our last annual convention, our Past President, J. B. Francis, gave us the key to the solution of the problem, and this was, that the material composing wheels and rails should not be subjected to pressures beyond their elastic limit. It is now over a dozen years since, in an evening's discus-

*Weight on each wheel is exclusive of weight of wheel.

sion with the late lamented C. Shaler Smith, M. Am. Soc. C. E., we had under consideration the subject of elasticity. The result of my calculations was, that driving wheels of locomotives, as then loaded, must have a diameter of about 17 feet, to keep the contact between it and the rail within the elastic limit. Calculations since made convince me that this was an under-estimate.

It is hardly necessary for me to direct your attention to the following sketch as illustrating our practice, as shown in Fig. 1, Plate XLIX. The author's proposed arrangement is shown in Fig. 2, without, however, endorsing the section of rail shown below the line, *A B*.

As children we listened with interest to the story of the genius shown in the invention of the coned wheel for railway purposes; and were told that without it curved lines could not be operated, etc. What are the facts? A new wheel, constructed in accordance with the rules of the Master Car Builders' Association, is coned to suit a curve of about 5 000 feet radius, and no other; and after six months' use, as shown by the preliminary report of your Committee, such wheels are either worn hollow at the flange or from the flange; so much so, that in at least one-third the instances, in passing curves, the inner wheel travels on its greatest diameter, and quite often the outer wheel travels on its least diameter—yet such wheels are operated safely. The German investigator Krüger (see Vol. 86, Inst. C. E.) proves by analyses what is apparent to all of us, that rolling friction is largely augmented through this device. I understand that the Association of Master Car Builders, at its meeting some two years ago, decided by a majority of three of the members in attendance at its convention to continue this practice; but that a large majority of those eminently practical men who were not in attendance were vigorously opposed to it.

The form of rail shown in Fig. 1, Plate XLIX, is that lately recommended by Sandberg for 100-pound rail, and which has a curved top of 6 inches radius, and from the sketch it is seen that, in so far as the elasticity wheel and rail will permit, it is about the best arrangement that can be devised to concentrate the stress on a point and have the travel of the wheel on a line. These are conditions that are revolting in a mechanical light—conditions we would not attempt to reproduce in almost any other mechanical device. While this condition prevails with new car wheels, engine drivers are generally turned cylindrical, and the work done by them and the car wheel tends to drive down this arch of the rail as a

wedge, and by flow of metal to make it flatter, at the same time producing characteristic curves of wear on the wheels, often resulting in shattering and piping the rail heads, with but little loss of material from direct wear. This flattening of the rail from an original radius of 10 or 12 inches to over 14 inches is well illustrated in the report of your Committee.

Mr. Octave Chanute, M. Am. Soc. C. E., many years ago gave us the results of his measurements of the area of contact between wheels and rails, and the writer quite recently made measurements in a similar manner, the results of which it may be proper to reproduce here. However crude the manner of taking the impressions may have been, I know of no other convenient method of securing them.

My first test was with an engine having four driving wheels, each carrying 16 000 pounds; diameter of wheels, 70 inches; tires much worn; and on a steel rail five years in constant service. A composite picture of all these apparent areas of contact shows an egg-shaped oval, having a major axis across the rail of $1\frac{48}{100}$ inches, and a minor axis along the rail of 1 inch, inclosing an area of $1\frac{7}{100}$ square inches.

My second test, with an engine having six driving wheels of 62 inches diameter, carrying 13 800 pounds, with tires that had been in service six months, gave a similar figure of contact, with a major axis of 1.27 inches and a minor axis of $\frac{70}{100}$ of an inch, inclosing an area of $\frac{86}{100}$ of a square inch. Through such contacts is transmitted the power exerted by our locomotives, not only in their direct compressive force, but also in their pulling capacity of, say, 4 000 pounds on the lamina of the rail. Is this the one spot in our earthly domain to which we cannot apply reason? The ingenuity of man has been able to formulate the approximate horsepower of the earthquake, finding the factors in shattered towers and dismantled homes; must that ingenuity stand appalled before this point of contact between wheel and rail? If so, we should exclaim with more effectiveness than did Lady Macbeth, " Out, damned spot!"

It is on this spot where, if the statement made in a paper now before this Society is construed literally, occurs that miraculous chemical action, "the molecular interlocking of the fibres" of a non-fibrous substance; but I suppose we all know the meaning intended by this sentence.

To me, and doubtless to many other members outside of some of your Committee, the solution of this problem rests in having a flat and
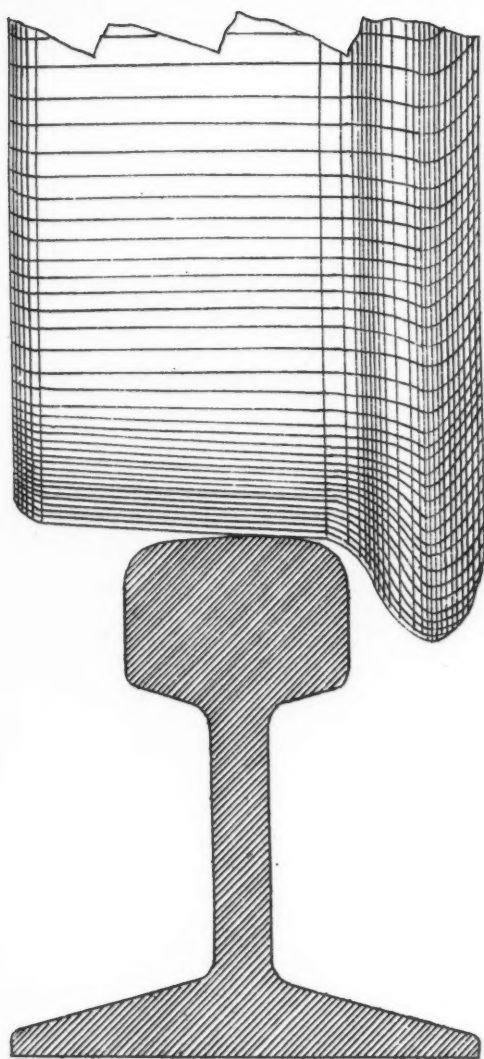
Fig. 1
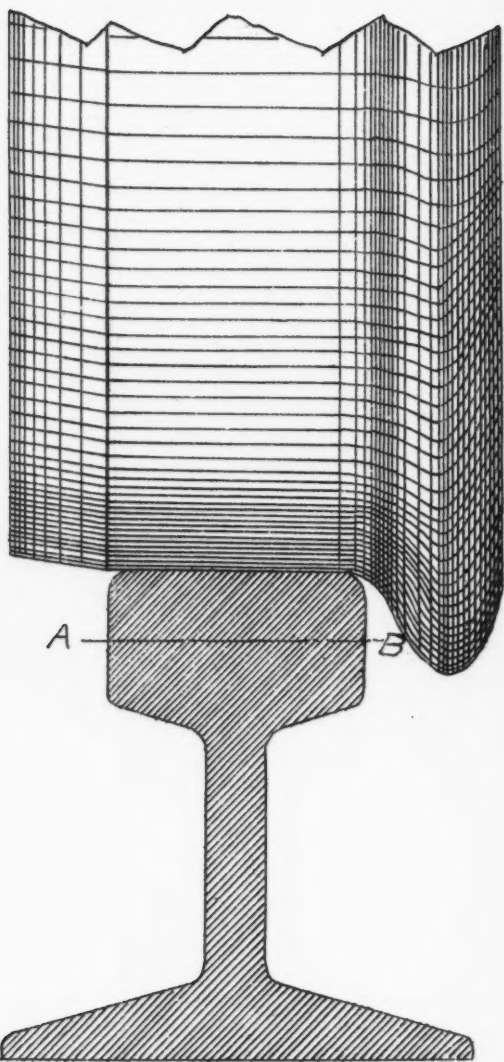Showing Present Practice

Sho

Fig. 2
Showing Suggested Arrangement
Above A. B.

sufficiently broad surface to the rail to support not conical but cylindrical wheels, to keep the pressures within the elastic limit of the metal. Right here we are met by the statement that it is not clear that "increased bearing surface is in itself an advantage;" and when we attempt anything like an analytical inquiry, we are met by *ex cathedra* statements "that to such bearing surfaces the ordinary compression moduli of the text books have no application whatever. * * * To apply these constants to the bearing surfaces of spheres or cylinders laid on their sides, or to draw conclusion that pressures exceeding them are therefore dangerous or destructive, is entirely unwarranted. No attempt has ever been made, nor can there well be, to determine constants for such round bodies, etc., and in good bridge practice it is considered entirely safe to load steel rollers rolling on steel up to the equivalent of 10 000 pounds per lineal inch for a 33-inch wheel."

I heartily wish that all abstruse questions in engineering were as well settled in the minds of engineers as these appear to be in the minds of some of your Committee. Ordinarily it is time wasted to attempt an argument before a jury that has already rendered its verdict on the important questions at issue; and I trust that this Committee will pardon me if I shall overcome my natural modesty, and appeal to those of my readers whose minds are open to conviction, to exercise patience while I call their attention to the labors, text book, and formulas of one more astute than the celebrated character in "Hudibras":

> "Who could distinguish and divide
> A hair twixt south and south-west side,
> And wisely tell what hour o' the day
> The clock does strike, by Algebra."

I mean Professor Frederick Grashof,* of the Polytechnic School at Carlsruhe, one of whose formulas has been extensively used in this country for determining constants for rollers on plane surfaces in nearly every first-class bridge specification for many years; and heretofore referred to by our Member, Mr. Charles Macdonald, with telling effect, in his criticism of C. Shaler Smith's, M. Am. Soc. C. E., paper on drawbridges, published in our Transactions as long ago as 1874, and in the

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* Theorie der Elasticitat und Festigkeit mit Bezug auf ihre Anwendungen in der Technik, von Dr. F. Grashof, Grossh. Badischer Geheimer Rath und Professor am Polytechinkum zu Carlsruhe.

same volume containing the report on rails made by our lamented Past President, Ashbel Welch, as Chairman, in which report is repeated six or eight times the necessity of securing greater width of contact between wheel and rail. In making use of these formulas in constructing the following table, the moduli was assumed by me at the values stated, after an examination of the tests made by our Member, Mr. Christie, and reported in our Transactions some years ago. It will be seen in the table of tests of steel in rails of the Chicago, Burlington and Quincy Railway, hereinafter given, that the modulus of resistance is somewhat lower than I have assumed in some instances, and much greater in others. I have utterly failed in my attempt to secure any data relating to the moduli of chilled cast-iron; hence you will consider the results of my calculations in this table as applying to steel wheels on steel rails. The table is not given as a play upon figures, but as an educator of the judgment. It has had that effect with me, and I trust it will not be without interest to others who have not given this subject their particular attention.

TABLE ON OPPOSITE PAGE, showing allowable pressures of wheels on rails with curved tops; also on rails with flat top surface.
Assuming different values of K and in which formulas

K = Elastic limit per square inch and such portion thereof as may be deemed safe; Designated $K_1 K_2 K_3 K_4$.
E = Modulus of elasticity of wheel.
E_1 = Modulus of elasticity of rail.
R = Radius of wheel.
R_1 = Radius of rail top.
P = Allowable pressure of wheel on rail. For rails with curved top the formula is

$$\pi \left(\frac{1}{E} + \frac{1}{E_1} \right) K^2 \sqrt{R R_1} = P.$$

For rails with flat top the formula is :

$$\sqrt{\frac{32}{9} \left(\frac{1}{E} + \frac{1}{E_1} \right)} K^3 R = P = \text{pressure per lineal unit of tread.}$$

In this table the assumed modulus of wheel tread 29 000 000, and for the rail 30 000 000.

TABLE No. 5.

Radii of Wheel and head of rail.		Weight on wheels, according to recent practice.	Assuming the value of K as stated, the weight on wheels can be as follows:				
Wheel.	Rail.		$K = 40\,000$	$K_1 = 35\,000$	$K_2 = 30\,000$	$K_3 = 25\,000$	$K_4 = 20\,000$
5″	8″	From 14 000 to 16 000 pounds, and in some instances 20 000 pounds.	5 722	4 367	3 212	2 225	1 422
5″	10″		6 398	4 882	3 591	2 488	1 590
5″	12″		7 008	5 348	3 934	2 725	1 741
5″	14		7 570	5 777	4 250	2 944	1 881
35″	16″		8 093	6 176	4 543	3 147	2 011
35″	18″		8 584	6 515	4 819	3 338	2 133
30″	8″		5 298	4 043	2 974	2 060	1 316
30″	10″		5 923	4 520	3 325	2 303	1 472
30″	12″		6 489	4 952	3 643	2 523	1 612
30″	14″		7 008	5 348	3 934	2 725	1 741
30″	16″		7 492	5 718	4 206	2 913	1 862
30″	18″		7 947	6 065	4 461	3 090	1 975
27″	8″		5 026	3 835	2 821	1 954	1 249
27″	10″		5 619	4 288	3 154	2 185	1 396
27″	12″		6 156	4 698	3 456	2 394	1 530
27″	14″		6 649	5 074	3 732	2 585	1 652
27″	16″		7 108	5 424	3 990	2 764	1 766
27″	18″		7 539	5 753	4 232	2 931	1 873
24″	8″		4 738	3 616	2 660	1 842	1 177
24″	10″		5 298	4 043	2 974	2 060	1 316
24″	12″		5 804	4 429	3 258	2 257	1 442
24″	14″		6 268	4 784	3 519	2 437	1 558
24″	16″		6 701	5 114	3 762	2 606	1 665
24″	18″		7 108	5 424	3 990	2 764	1 766
21″	8″	Sleeping and dining cars, 6000 to 6500 pounds.	4 432	3 382	2 488	1 723	1 101
21″	10″		4 955	3 782	2 782	1 927	1 231
21″	12″		5 429	4 143	3 048	2 111	1 349
21″	14″		5 863	4 475	3 292	2 280	1 457
21″	16″		6 268	4 784	3 519	2 437	1 558
21″	18″		6 649	5 074	3 732	2 585	1 652
16½″	8″	Passenger and sleeping cars, 5 500 to 6 500 lbs. Freight cars from 8 000 to 11 500 lbs, and for rotary snow plows, 16 000 lbs.	3 929	2 998	2 205	1 528	976
16½″	10″		4 392	3 352	2 466	1 708	1 091
16½″	12″		4 812	3 672	2 701	1 871	1 196
16½″	14″		5 198	3 966	2 918	2 021	1 291
16½″	16″		5 556	4 240	3 119	2 160	1 381
16½″	18″		5 894	4 498	3 308	2 292	1 464
35″	Flat top		23 243	19 025	15 097	11 482	8 134
30″	"		21 519	17 614	14 086	10 630	7 530
27″	"		20 415	16 710	13 260	10 085	7 144
24″	"		19 248	15 755	12 502	9 508	6 736
21″	"		18 006	14 738	11 695	8 895	6 301
16½″	"		15 959	13 063	10 366	7 884	5585

These formulas for the values of K, K_1, K_2, K_3 and K_4 can be reduced to expressions as follows, viz.:

FOR CYLINDER ON CYLINDER:

$K = 40\,000.\quad P = 342\,\sqrt{R\,R_1}$

$K_1 = 35\,000.\quad P = 261\,\sqrt{R\,R_1}$

$K_2 = 30\,000.\quad P = 192\,\sqrt{R\,R_1}$

$K_3 = 25\,000.\quad P = 133\,\sqrt{R\,R_1}$

$K_4 = 20\,000.\quad P = 85\,\sqrt{R\,R_1}$

FOR CYLINDER ON FLAT TRACK:

$P = 3929\,\sqrt{R}$

$P = 3216\,\sqrt{R}$

$P = 2552\,\sqrt{R}$

$P = 1941\,\sqrt{R}$

$P = 1375\,\sqrt{R}$

The formula I wish to call your attention to first, is that which applies to cylinders in contact and having their axes transversely to each other—precisely the condition that prevails with wheels and rails. It may be claimed that the moduli assumed are not correct. My answer is, assume any other within reason, and then deduce results. It is true that these formulas apply to the cylinder or wheel, but in degree they apply with equal force to the rail; or, to put it in the language of a late editorial in the *Engineering News* on this question: "It is a fair presumption that whatever wears the rail most wears the wheel most."

No words of mine are needed to give weight to the deduction that can be drawn from this table. Of course it is nonsense to contemplate the use of driving wheels of 30 feet and over in diameter to keep within the elastic limit of rails having a rounded head of 12 inches radius. Note what results are given for wheels on flat surfaces. Please bear in mind that these figures apply only to static conditions of loads; what should be the practice when we add that indefinite quantity due to momentum or impact, imperfect wheels and track, and unbalanced locomotives at high speeds? Our wonder is not that rails fail so soon, but that they last so long!

It is my claim that this table at once suggests the remedy—which is, that without the necessity of increasing diameter of wheels, we should provide a contact between wheel and a flat surface of rail of from $2\frac{1}{4}$ to $2\frac{1}{2}$ inches wide, making the total width of head, after providing for corner curves, from $3\frac{1}{4}$ to $3\frac{1}{2}$ inches. In arriving at this conclusion I have taken for my factor of safety that given in the use of the value of K_3, although that derived from K_4 corresponds, in my opinion, more nearly with good bridge practice—the statement of some of your Committee to the contrary notwithstanding.

The merit I attach to these formulas rests not alone in their deter-

mination through rigid analytical and logical reasoning, but that they accord with common sense.

It is true, as reported by your Committee, that our rails fail with little material abraded from the top. The fact is, they are crushed, after flow of metal has reached its limit; they fail, like all other crystalline substances when overtaxed, by rapid disintegration and not abrasion, and it is the exception to find in the scrap heap a rail with the head well worn down.

If my premises are correct, that a wider bearing surface is necessary, the question naturally arises, can such forms be rolled? A way is always found to do that which must be done ; but if this width of rail head shall prevail, then the indications are that the Sandberg pattern of T rail—with its sacrifice of from one to two pounds per yard in reinforcing the two cantilevers of its head to accommodate splice bars that, in themselves, restore the rail to only one-half of its strength as a girder where intact—must be a thing of the past.

Fig. 3.
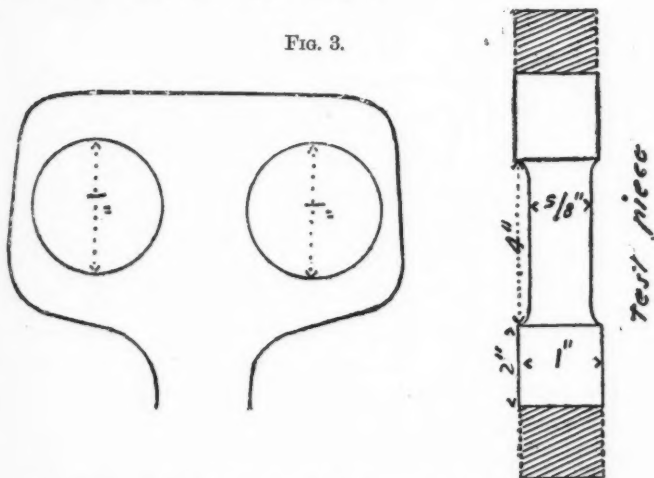
In search of moduli for use in Professor Grashof's formulas, I have secured, again through the kindness of Mr. G. W. Rhodes, of the Chicago, Burlington and Quincy Railway, the results of test specimens, cut from the heads of new and old rails, which are given in the following table:

I have also secured (from George Gibbs, Mechanical Engineer of

the Chicago, Milwaukee and St. Paul Railway Company) tests, chemical analyses and photographic representations of etched rails that have received severe service, which are given in the following table and sketches:

TABLE No. 6.

Test of Rail, Chicago, Burlington and Quincy Railway.

When Made.	Maker.	Weight per Yard. Pounds.	Tensile Strength in pounds per square inch.	Elastic limit per square inch.	Per cent. Elongation in 4 inches.	Old or New Rail.
1887	F	66	119 000	60 100	10.15	New
1887	F	66	120 800	61 500	9.30	"
1887	F	66	124 100	65 800	9.00	"
1887	F	66	126 700	68 100	6.25	"
1887	F	66	107 022	55 100	12.10	"
1887	F	66	104 400	55 800	6.25	"
1887	F	66	120 437	63 400	9.96	"
1887	F	66	120 100	62 900	10.15	"
1871	F	66	75 350	42 000	16.40	Old
1871	F	66	66 130	38 700	9.40	"
1878	F	66	76 800	45 600	19.50	"
1878	F	66	79 600	50 500	18.75	"
1878	F	66	80 000	50 700	20.00	"
1878	F	66	76 000	47 100	20.00	"
1878	F	66	76 200	44 300	22.26	"
1888	A	66	87 900	40 000	18.00	New
1888	A	66	87 200	39 900	18.35	"
....	G	60	101 500	42 414	6.25	Old
1879	A	66	114 900	52 800	14.18	"
1880	F	66	74 606	35 185	30.00	"
1880	H	66	81 150	36 200	26.56	"
1882	I	66	92 300	46 500	15.60	New
1884	I	66	106 400	78 300	.....	"
1885	C	66	109 800	51 600	12.08	"
1885	C	66	111 200	52 600	14.38	"
1886	A	66	102 700	52 000	15.62	"
1886	J	66	93 300	48 132	21.00	"
1886	J	66	126 200	65 235	10.00	"
1879	K	56	80 285	37 650	22.00	Old
1879	K	56	81 280	38 100	21.50	"
1880	H	66	83 800	......	21.00	"

It will be observed that these tests do not show any remarkable change through use. I take it as a fact that the cutting of test specimens relieves them from the internal stresses, as is supposed to be the case in reaming punched rivet holes in steel plates.

While the appearance of the photographic etchings can be sometimes observed in new rails, owing, as is believed, to faulty manufacture or of design, yet fractures of this rail before use did not show such defects of structure. It is the slow but fatal development of an internal organic disease in a structure that is not organic, if we may borrow an idea from a present report—a sort of tuberculosis disease, with its slow-forming cavities. (Plates LI, LII, LIII, LIV, LV.)

TESTS OF STEEL RAILS, CHICAGO, MILWAUKEE [

Vol XXI, page 148.

Laboratory Number.	Number on Section.	Material.	Maker.	Per cent. of Carbon.	Per cent. of Manganese.	Per cent. of Silicon.	Per cent. of Phosphorus.	Per cent. of Elongation.	Tensile Strength, pounds per sq...
......	....	56-pound steel rail.	....	.35	1.35	.025	.069	......	......
......	......	60 " "	....	.45	1.63	.075	.056	......	......
63 b	1	67 " "	A	.263	0.35	.050	.123	1.	73
64 "	2	67 " "	B	.250	0.56	.019	.068	4.	109
65 "	3	68 " "	B	.283	0.40	.013	.060	3.	89
66 "	4	60 " "	A	.211	0.44	.025	.113	23.	88
72 "	9 and 10	"	C	.344	0.83	.198	.095	0.	82
73 "	11 and 12	"	C	.241	0.55	.013	.077	21.	83
76 "	13 and 14	"	C	.278	0.50	.043	.108	9.	83
77 "	15 and 16	"	D	.297	0.87	.047	.063	9.	91
120	17 and 18	60 " "	A	.34	0.64	.063	.146	21.	83
121	19 and 20	60 " "	A	.42	0.92	.082	.129	7.	88
122	21 and 22	60 " "	A	.46	0.97	.105	.071	15.	109
123	23 and 24	60 " "	A	.48	0.99	.065	.146	2.	80
124	25 and 26	60 " "	A	.35	0.84	.119	.140	17.	97
125	27 and 28	60 " "	A	.39	0.72	.097	.157	21.	91
161	31	"	A	.39	1.02	.070	.149	......	......
162	29 and 30	"	A	.39	1.08	.103	.150	19.	99
197	32 and 33	"	A	.45	1.35	.098	.181	1.	86
303	34	67 " "	C	.41	0.69	.034	.055	......	......
526	35	75 " new "	E	.28	0.274	.108	.108	23.	88
534	36	75 " " "	A	.36	1.55	.030	.067	7.	114
547	37	60 " "	F	.39	1.52	.046	.066	14.	108
548	38	60 " "	C	.52	1.97	.063	.074	5.	120
549	39	75 " new "	E	.27	0.68	.227	.088	21.	87
555	40	"	D	.48	1.00	.020	.076	17.	102
556	41	67 " "	D	.50	0.94	.021	.069	2.	84
558	42	60 " "	B	.50	1.15	.026	.068	15.	121
807	43	75 " "	E	.326	0.499	.150	.136	......	......
808	44	75 " "	E	.266	0.536	.256	.146	......	......
809	45	75 " "	E	.332	0.504	.172	.149	......	......
810	46	75 " "	E	.288	0.543	.232	.139	......	......

NOTE —Nos. 123, 124 and 125 were
and best when taken out.

Nos. 120, 121 and 122 were betwee

The following analyses of three s

Analysis No. 1, made from a pie
    cent.; P., 0.132 per cent.; S.,

Analysis No. 2, made by "A" thi
    per cent....................

Analysis No. 3, an average analy
    S., 0.03 per cent.............

Test specimens were cut from he

December 29th, 1888.
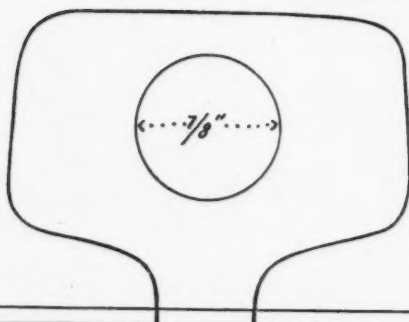
TABLE No. 7.

Per cent. of Manganese.	Per cent. of Silicon.	Per cent. of Phosphorus.	Per cent. of Elongation.	Tensile Strength, pounds per square inch.	When Laid.	When Removed.	Color and Grain of Fracture.
1.35	.025	.069	.....	....	....	....	....
1.63	.075	.056	.....	....	....	....	....
0.35	.050	.123	1.	73 200	Sept., 1884	....	....
0.56	.019	.068	4.	109 500	1886	April, 1887	....
0.40	.013	.060	3.	89 900	July, 1886	April, 1887	....
0.44	.025	.113	23.	88 600	Sept., 1884	July 15th, 1887	....
0.83	.198	.095	0.	82 100	Mar., 1883	1887	Marked rail w
0.55	.013	.077	21.	83 900	....	Sept., 1887	....
0.50	.043	.108	9.	83 100	June, 1883	Oct. 4th, 1887	....
0.87	.047	.063	9.	91 900	June, 1886	Sept. 26th, 1887	....
0.64	.063	.146	21.	83 500	Oct., 1878	July, 1887	Dark gray, fine
0.92	.082	.129	7.	88 000	Oct., 1878	July, 1887	Light gray, co
0.97	.105	.071	15.	109 200	Oct., 1878	July, 1887	Darker than 12
0.99	.065	.146	2.	80 400	Oct., 1876	June, 1887	Light gray, rat
0.84	.119	.140	17.	97 700	Oct., 1876	June, 1887	" fine
0.72	.097	.157	21.	91 700	Oct., 1876	June, 1887	"
1.02	.070	.149	.....	....	....	....	Short end.
1.08	.103	.150	19.	99 500	....	....	Dark color, fine
1.35	.098	.181	5.	86 900	Sept., 1886	Sept., 1887	Bright fracture
0.69	.034	.055	.....	....	June 7th, 1883	Feb. 9th, 1888	....
0.67	.274	.108	23.	88 400	....	....	Dark gray, fine
1.55	.030	.067	7.	114 900	....	....	White and rath
1.52	.046	.066	14.	108 500	....	....	Gray, fine grai
1.97	.065	.074	5.	120 200	....	....	White and rath
0.68	.227	.088	21.	87 700	....	....	Fine grain, sm
1.00	.020	.076	17.	102 300	....	....	" gra
0.94	.021	.069	2.	84 600	....	....	White, coarse
1.15	.026	.068	15.	121 700	....	....	Almost white,
0.499	.150	.136	.....	....	....	....	Short end.
0.536	.256	.146	.....	....	....	....	"
0.504	.172	.149	.....	....	....	....	"
0.543	.232	.139	.....	....	....	....	"

NOTE —Nos. 123, 124 and 125 were between Langdon and Newport, Minn., laid on a 2?
d best when taken out.

Nos. 120, 121 and 122 were between Read's Landing and Wabasha, laid on about a lev

The following analyses of three samples of 75-pound rails were made at Laboratories

Analysis No. 1, made from a piece of 75-pound rail that came from "E," was: C.,
cent.; P., 0.132 per cent.; S., 0.053 per cent..

Analysis No. 2, made by "A" this year, was: C., 0.391 per cent.; Mn., 1.31 per cent.;
per cent...

Analysis No. 3, an average analysis made at "E," was: C., 0.29 per cent.; Mn., 0.40
S., 0.03 per cent..

Test specimens were cut from head, as shown, turned down to ¾ inch diameter 5 inc

December 29th, 1888.

Color and Grain of Fracture.	Dr. Dudley's Phosphorus Units.
....	....
....	....
....	30.6
....	26.2
....	24.5
....	28.4
d rail west, bright.	47.5
....	27.0
....	32.8
....	36.4
gray, fine grain.	41.8
gray, coarse grain.	49.4
than 121, coarser.	47.0
gray, rather coarse.	53.6
fine grain.	58.3
"	47.9
nd.	51.8
olor, fine grain.	54.7
fracture, fine grain.	65.0
....	34.6
gray, fine grain.	47.2
and rather coarse.	51.2
fine grain.	52.3
and rather coarse.	49.3
rain, small bead.	42.7
gray.	44.6
coarse grain.	43.3
t white, fine grain.	47.7
nd.	42.0
	46.9
	44.7
	45.9

d on a 26-foot grade, oldest and best steel on River Division,

out a level.

ratories at "A" and "E":

was: C., 0.30 per cent.; Mn., 0.74 per cent.; Si., 0.227 per 49.3

er cent.; Si., 0.045 per cent.; P., 0.114 per cent.; S., 0.071 ....52.8

Mn., 0.40 per cent.; Si., 0.165 per cent.; P., 0.09 per cent.; 34.8

ter 5 inches long.

GEORGE GIBBS,
Mechanical Engineer.

60-Pound Steel Rail.

Laid September, 1884. Removed July 15th, 1887.

Carbon...............................0.21 per cent.
Manganese............................0.44 "
Silicon..............................0.025 "
Phosphorus...........................0.113 "
Sulphur..............................0.025 "

 T. S..................88 600 pounds per square inch.
 Elongation...........23 per cent. in 5 inches.

PLATE LI.   No. 2.

60-Pound Steel Rail.

Laid October, 1878.   Removed July, 1887.

Carbon	0.42	per cent.
Manganese	0.92	"
Silicon	0.082	"
Phosphorus	0.129	"

T. S.................88 000 pounds per square inch.
Elongation............7 per cent. in 5 inches.

PLATE LII.   No. 3.

60-Pound Steel Rail.

Laid October, 1876.   Removed June, 1887.

Carbon...................................0.48 per cent.
Manganese ....0.99   "
Silicon..................................0.065   "
Phosphorus ....0.146   "

T. S..................80 400 pounds per square inch.
Elongation............2 per cent. in 5 inches.
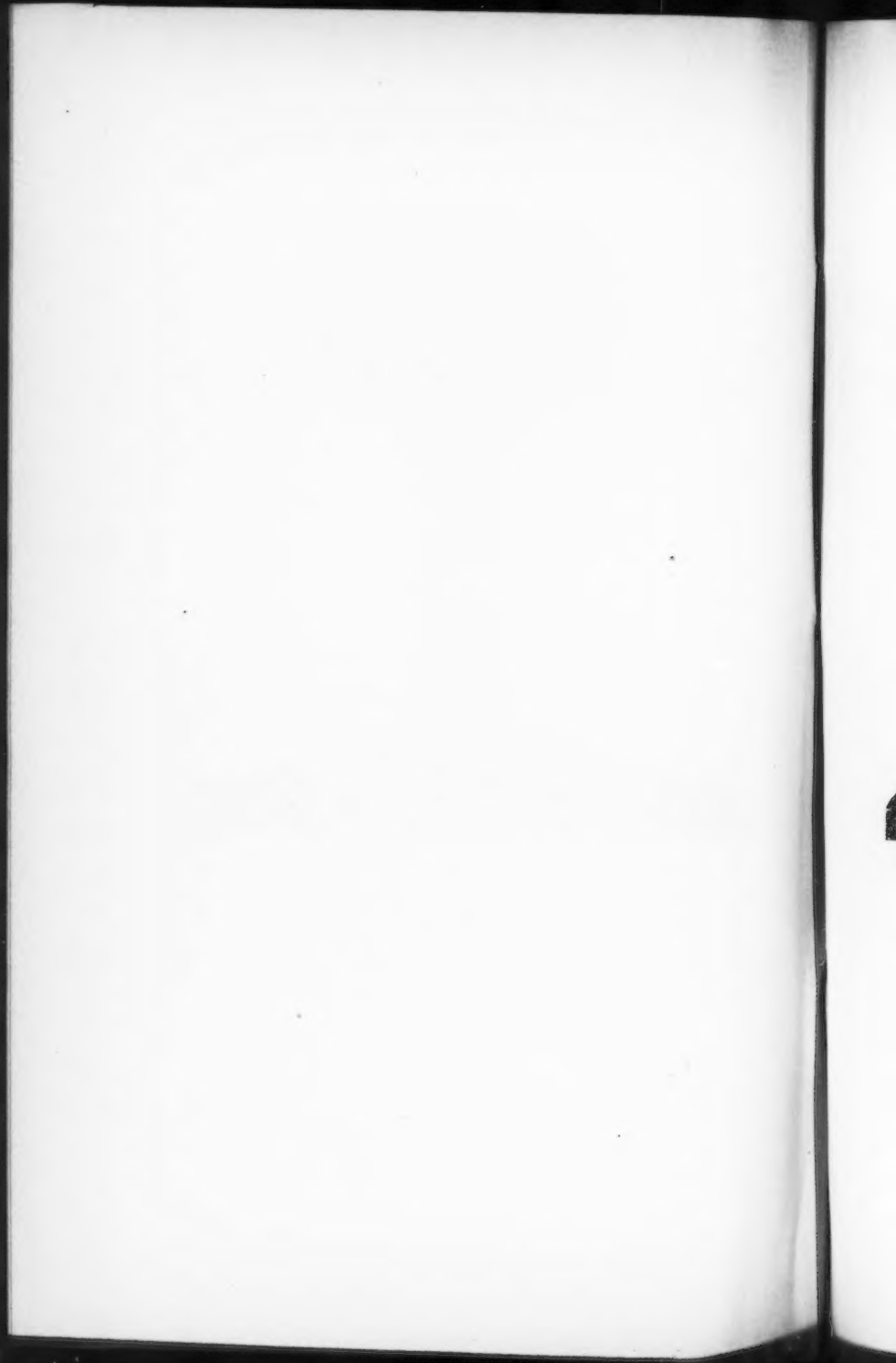
PLATE LIII.   No. 4.

60-Pound Steel Rail.

Laid October, 1876.   Removed June, 1887.

Carbon....................................0.35 per cent.
Manganese..............................0.84   "
Silicon...................................0.119   "
Phosphorus........... ....0.140   "

    T. S...................97 700 pounds per square inch.
    Elongation ....17 per cent. in 5 inches.

PLATE LIV.   No. 5.

Caused Wreck at Rosemount.

Carbon.....................................0.39 per cent.
Manganese ....1.02   "
Silicon....................................0.070   "
Phosphorus ....0.149   "

It is beyond the intended scope of this paper to treat of the chemical composition of steel rails; yet it may be proper for me to incorporate an extract from a letter just received from the able manager of the Union Steel Company of Chicago, Mr. Robert Forsyth, M. Am. Soc. C. E., as follows: "In regard to your inquiry as to the analyses of steel, I will say that we aim to make rail steel with: Carbon, .32 to .40 per cent.; silicon, .04 to .06; phosphorus, .09 to .105; manganese, 1.00 to 1.50 per cent. The amount of manganese is varied from time to time to suit the character of the metal we may happen to be using. We have made a great deal of steel with phosphorus lower than .09, but we cannot, as a rule, do better, nor do I think it necessary for rails."

As a matter of curiosity he sends me two analyses of rails, made not long ago, in which he determined a large number of substances not ordinarily looked for in steel. These analyses should not be considered typical of his manufacture, however. They are as follows:

ANALYSES OF TWO SAMPLES OF RAIL STEEL.

	No. 1. Per cent.	No. 2. Per cent.
Carbon	.410	.390
Manganese	1.45	1.500
Silicon	.069	.063
Phosphorus	.098	.092
Sulphur	.046	.055
Copper	.007	.022
Titanium	.000	.000
Calcium	.004	.001
Magnesium	.001	Trace
Aluminium	.010	.008
Arsenic	Trace	Trace
Antimony	Trace	Trace
Cobalt } Nickel }	.0013	.0011
Specific Gravity	7.83972	7.84395

It is justly claimed by the managers of rail mills that the engineer of permanent way is deficient in knowledge of what practicable forms can be rolled with good results; and it is also natural to suppose that the proprietors of these works desire to limit their output to the amount of metal that can be squirted through their rolls in the shortest possible time, and have the same accepted.

We find, however, from an examination of forms sent us by rolling mill managers, that they can roll, with uniformly good results, as great

a diversity of disposition of metal as the engineer of permanent way offers in his plans. This, however, is a branch of the subject of which it is not the purpose of this paper to treat. To such as wish light on this branch I refer to the paper on steel rails, by our Member, Robert W. Hunt, read before the American Institute of Mining Engineers in October last, in which it will appear that all the ills the rail is heir to cannot be attributed to the error of its curved top; neither do I so claim, but I do assert that whether the material be good or bad, better service will be secured when this error is eliminated.

On Plate LV are shown sketches of sections of rail taken from a scrap heap showing how rails fail with little abrasion.

These rails were of the very best quality and had been in service for nine years. Measurements taken of twenty of them show a wear of less than $\frac{1}{32}$ of an inch, and the loss of weight about 1 pound per yard. How much of this was due to corrosion and how much to abrasion we do not know, but I venture to say that there was twice as much from corrosion as from abrasion. Giving these sections the curve in head that they originally possessed, and with the web projecting into it, can we devise a better form for splitting the rail from the weight imposed by the wheel than is presented? Yet this is typical of universal practice. If my premises are true, we now see why 33 and 42-inch wheels, under our passenger equipment, render so much greater service than we have from the rail, which is subjected to pressures far beyond the elastic limit, through freight car wheels and engine drivers. The wear of engine drivers shows better results than that of rails; but it must be remembered that there is from two to three times the metal in their cross-section than in the rail; that there is a greater field for flow and disposition of stresses in the former than in the latter; and yet it is not an unheard-of thing for driver tires to pipe and split. In comparing wheel with rail service, it should be borne in mind that the estimates given of tonnage service of rail apply to the two parallel rails, and not to one rail only.

The fact is that there is hardly a wheel turning under our freight cars when loaded to their scheduled capacity, or a driver under our locomotives, that does not strain the metal in the rail beyond its modulus of resistance. From the tests given we can safely assume that for the majority of our rails this modulus can be taken at 45 000 pounds. In many instances it falls below 40 000. With a modulus of 45 000
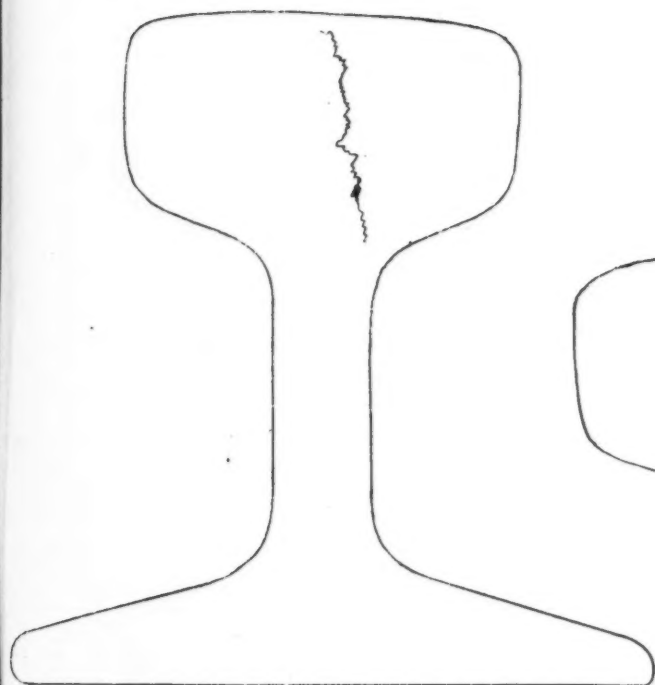
SECTION CUT FROM BEYOND END OF RAIL.
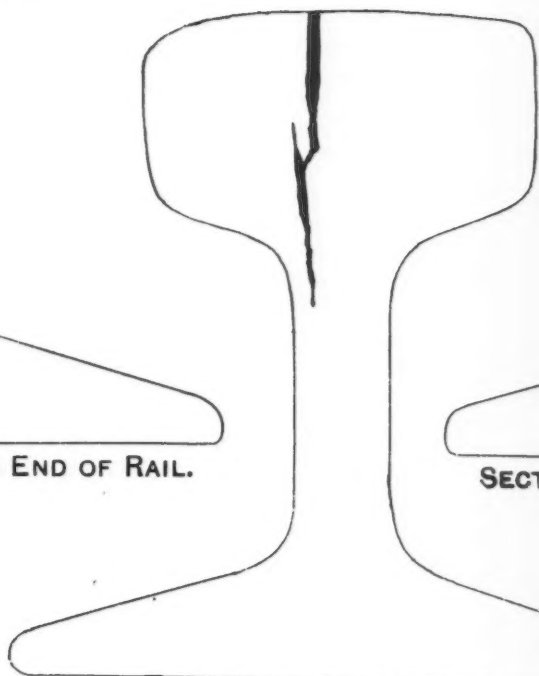
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SECTION AT END OF RAIL.
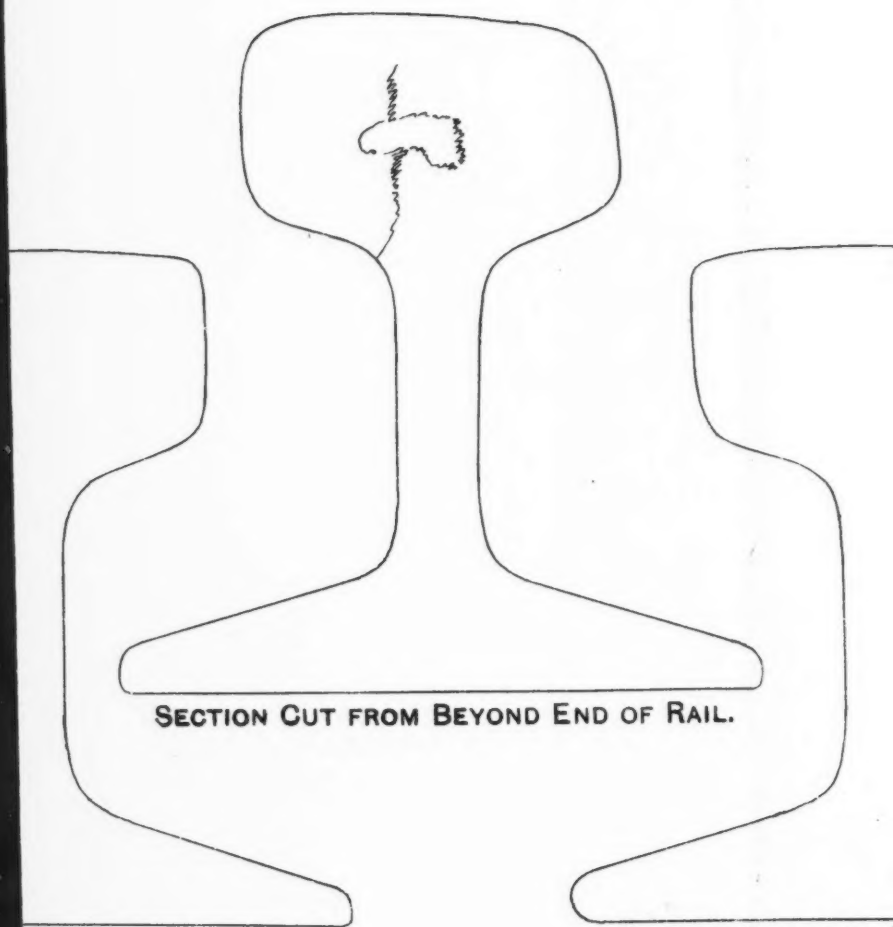
SECTION CUT FROM BEYOND END OF RAIL.

END OF RAIL.

SECTION CUT FROM
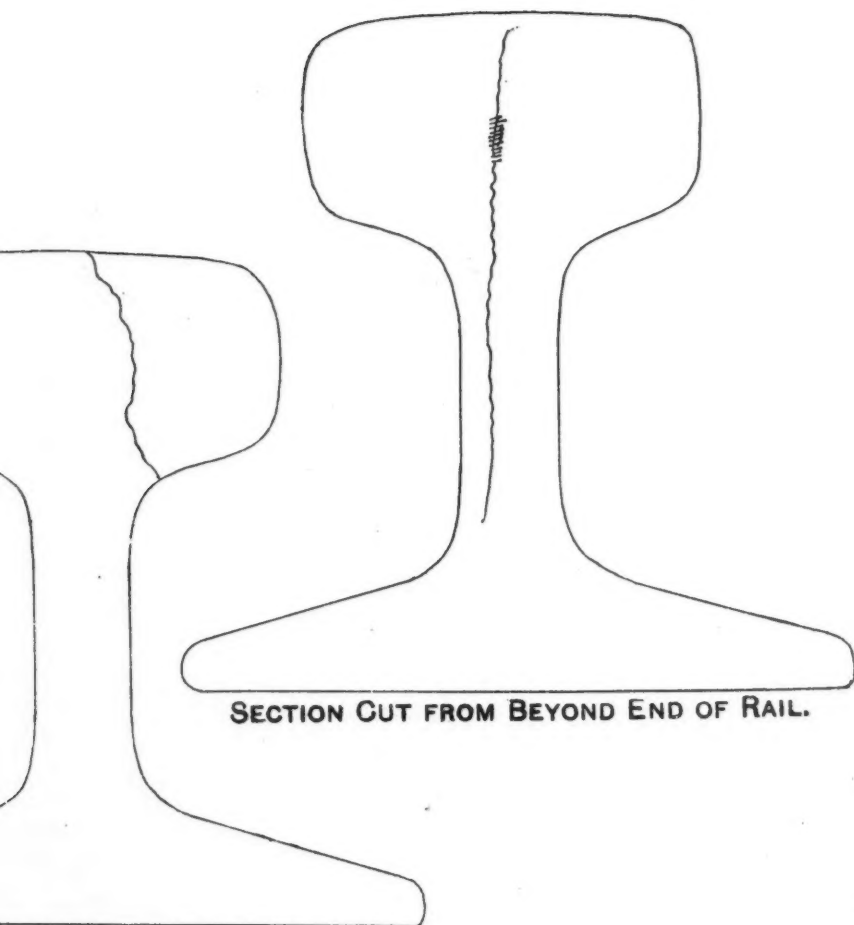
SECTION CUT FROM BEYOND END OF RAIL.

FROM BEYOND END OF RAIL.

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pounds the car wheel can sustain about 6 000 pounds within the elastic limit, and this approximates to the weight on passenger equipment ; hence the high service shown for the steel tired wheel.

Undoubtedly, many of our older members have seen the iron rail of twenty-five or thirty years ago wear down nearly one-half inch ; many of them have observed, and I have measured the wear of steel rails when first introduced, and when lighter loads prevailed, a wear of $\frac{3}{8}$ of an inch before they found a resting place in that charnel-house, the scrap heap ; now, under present loads, their usefulness ends with from ten to forty or fifty million tons' service. Some one spot on our overloaded engine tires wears down $\frac{1}{8}$ of an inch after a service of from twenty to forty million tons, while the steel tired passenger car wheel, which is loaded to about its elastic limit, gives a tonnage service of from one hundred and fifty to two hundred million for the same wear, nearly the whole of which wear we can reasonably attribute to the action of brake shoes and slipping of wheels, and not to abrasion due to normal conditions of rail and wheel contact.

In regard to the fillet curve of wheel flange, it is my belief that the decision of your Committee is correct—that it should not be the same as the curve of rail corner; that flange pressures should be confined, as near as possible, to the origin of the curve, with the tread of wheel ; and where abrasion caused by increased periphery is the least, and also where leverage to resist stress is the most effective.

We should seriously consider the propriety of adding in any way whatever to the duty of the flange—a projection of only a trifle over 1 inch—the agent between us and disaster as we rush through space at fearful velocity. I venture to say that there is not a flange on a cast-iron wheel that cannot be knocked off, without excessive effort, by a hammer in the hands of any person in this room.

To me it appears self-evident that rolling resistance is decreased with wheels running within the elastic limit ; that once wheels are of equal diameter, they will longer remain so than by the present practice ; and that, therefore, the tendency of wheels to run to flange will not be nearly so great as now. The larger wheel always drags the smaller when on the same axle.

It strikes the writer that heretofore the engineer of permanent way has had just enough of the æsthetic in his nature to desire to top out his work by a graceful curve, leaving the purely mechanical engineer

to meet the condition it induces as best he could ; and I take it as the duty of the civil engineer, *per se*, the real conservator of power and matter, to meet this condition.

Looking at the rail on end, in cross-section, we find it a very small affair, 6 or 8 square inches in area, and my matter treats of but a few hundredths of this area ; but when looked at in longitude, we find that it has a length of over 600 000 miles, every inch of which contains, as I believe, a blunder in design.

If this opinion is a correct one, then it is the duty of our profession to hasten the slow processes of evolution and eradicate this evil in the shortest practicable time. This cannot be done at once—rails and wheels now in service will remain until their usefulness is past. The flat topped rail adopted by any single line will receive the imprint of wheels worn hollow in tread by service on round-topped rails ; but I believe if those responsible agents of lines forming any one of our great transcontinental routes make earnest effort in this direction, the evil will soon be practically overcome. Already an earnest effort is being made by several managers and engineers of several important corporations to secure uniformity of rail sections.

It is believed that the change of form of rail contemplated in this paper will not involve the use of any more material than is now used on many of our railways. That dear old lady, Mrs. Partington, said that when the horse ran away with her, she trusted in Providence until the breeching broke, and then she jumped. The traces of our railways are now at their fullest tension, possessing no factor of safety within the elastic resistance. Have we not trusted in Providence too long in our violation of a law of nature ? Is it not our duty to be prepared to quickly leap, not into the dark, but into the light of reason, to avoid disaster that will, that does, result from present practice ?

If a change is necessary, why not have our form of rail a type of that noblest of all creations, a level-headed man with two legs and feet to correspond ? Why not come back to the design of the American Strickland of 1834, re-designed by Brunel in 1835, and still in use on the Great Western Railway of England ? While I am not prepared to express the opinion that the rail of the future will have this similarity, it goes without saying that disaster surely follows any attempt to work material substances, as well as our mental faculties, beyond their elastic limit.

TRANSACTIONS.

Note.—This Society is not responsible, as a body, for the facts and opinions advanced
in any of its publications.

DISCUSSION

ON

CYLINDRICAL WHEELS AND FLAT TOPPED RAILS FOR RAILWAYS.*

JAMES B. FRANCIS, Past President Am. Soc. C. E.—I have had little
or no practical experience in the wear of rails and the tires of wheels
rolling on them, but there are some general ideas that occur to me bear-
ing on the matter.

Assuming that the top of the rail is curved in section, and the tire
conical as represented by Fig. 1, Plate XLIX,† if the forms are perfect and
the material of both incompressible, they would touch only in a point,
where the pressure per square inch would be infinite. They are, how-
ever, both compressible, the effect of which is to form depressions on
both surfaces, and to distribute the pressure over an area, the extent of
which depends on the degree of compressibility. The pressure per
square inch would be very unequal at different parts of this area, being
greatest at the first point of contact, and diminishing from this point to
the edges of the depressions, where it would be nothing.

If the forms of the rail and tire are as represented by Fig. 2, Plate
XLIX, the contact, if the material is incompressible, would be a line,
on every point of which the pressure per square inch would be infinite,
and if compressible, depressions would be made, having this line for

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* Cylindrical Wheels and Flat Topped Rails for Railways, by D. J. Whittemore, Trans.
Am. Soc. C. E., Vol. XXI, p. 133, September, 1889.

† Transactions, Vol. XXI, p. 142, September, 1889.

an axis, where the pressure per square inch would be the greatest, and at the edges of the depression it would be nothing.

The area of the depression would be greater, and its maximum depth less, in the case represented by Fig. 2 than by Fig. 1, and the total pressure being the same in both cases, the mean pressure per square inch of the depression would be proportionally less in Fig. 2.

I think the destructive effect of the pressure on the rail and tire is substantially proportional to the maximum pressures which would be obviously greater in Fig. 1 than in Fig. 2.

The above applies only to the case where the surfaces are unworn, and the motion uniform both in velocity and direction; practically these conditions are far from being fulfilled. The effect of use on Fig. 1, I think, must be to approximate to Fig. 2, and it would appear to be best to adopt that form, or something near it, to begin with.

On page 146 of the paper, after describing the great variations in the forces, it is remarked: " Our wonder is, not that rails fail so soon, but that they last so long." My idea is that the destructive effects of pressure, impact, etc., are largely modified by their distribution through the mass of the head of the rail; the application of the pressure or impact would usually be on a small area of the top of the rail, and the pressure would be sufficient to crush an isolated prism with a base of that area; to be crushed, however, it must spread laterally, which is prevented to a great extent by the adjacent parts of the head of the rail, and instead of crushing the prism, by the elasticity of the metal a large part of the effect is transferred to other parts of the head of the rail. If the point of contact is near one side of the head of the rail, the prism would have less support from adjacent parts, and these parts of the head would be the weakest.

M. J. BECKER, President Am. Soc. C. E.—The statements contained in the introductory sentences of Mr. D. J. Whittemore's paper on "Cylindrical Wheels and Flat Topped Rails for Railways" must certainly be accepted without controversy. It is true that the wheel-loads are larger than ever before, and it is not at all likely that they will ever be reduced; it is equally true that the rail sections have not been increased in proportion to the heavier loads imposed, and that the rails are therefore subjected to stresses somewhat beyond their proper resisting capacity.

While I agree with Mr. Whittemore thus far, I am not prepared to admit either the full extent of the consequences due to these admitted facts, nor do I quite agree with his views regarding the efficiency of the remedies he suggests.

In the first place, the wheels and rails which are annually consigned to the scrap heap, and the value of which he estimates at a billion of dollars every few years, are by no means a total loss. As far as the old rails

are concerned, they bear, at present prices, a proportion to the value of new rails, of about 22 to 28.

Assuming the total mileage of all tracks (main, second and yard tracks) in this country at 300 000 miles, and counting 100 tons per mile, we would have an aggregate of 30 000 000 tons of rail. Assuming, further, the average life of rail in all these tracks at fifteen years, the annual renewal would amount to 2 000 000 tons, and the absolute loss, resulting from the difference in value between old and new rail, at say $6 per ton, would be $12 000 000 per annum.

The number of wheels attached to our combined rolling stock and motive power is about 8 000 000, and their aggregate weight is about 2 500 000 tons; the wheels annually broken and condemned for all causes amount to about 300 000 tons, and the difference in value between scrap and new wheels is nearly $13 per ton, so that the actual annual loss in wheels would foot up to about $3 900 000. This, together with the $12 000 000 for rails, gives us $15 900 000; an amount very far from Mr. Whittemore's billion. Indeed, the total value of all tracks and wheels in the country does not amount to anything like a billion. Still the value of the annual scrap heap amounts to quite a large sum, and if it can be reduced, it ought certainly to be done.

But let us take a look at the other side of the picture and see what has been gained by the adoption of heavier power and larger carriages.

COMPARATIVE STATEMENT OF ENGINE AND CAR MILEAGE, TONNAGE AND TON MILEAGE, FOR YEARS 1873, 1878, 1883 AND 1888, AND PERCENTAGE OF INCREASE OR DECREASE COMPARED WITH 1873.

PITTSBURGH, FORT WAYNE AND CHICAGO RAILWAY.

	1873.	1878.	Per cent.	1883.	Per cent.	1888.	Per cent.
Engine mileage ...	5 751 670	4 415 830	− 23.2	5 202 559	− 9.5	3 961 950	− 31.1
Car mileage........	70 654 926	92 533 418	+ 30.9	116 958 485	+ 65.0	116 112 930	+ 64.3
Tonnage	2 292 644	3 026 250	+ 32.0	5 076 311	+121.5	6 210 816	+170.9
Ton mileage	479 917 429	637 470 506	+ 32.8	944 563 376	+ 96.8	1 004 657 034	+109.3

PITTSBURGH, CHICAGO AND ST. LOUIS RAILWAY.

	1873.	1878.	Per cent.	1883.	Per cent.	1888.	Per cent.
Engine mileage ...	2 312 780	2 037 633	− 11.8	2 672 601	+ 15.5	2 803 974	+ 21.2
Car mileage	36 189 869	40 376 875	+ 11.5	48 437 358	+ 33.8	66 332 026	+ 83.2
Tonnage	1 472 709	2 142 155	+ 45.4	3 466 544	+ 67.4	5 239 796	+255.8
Ton mileage.......	205 508 887	287 757 418	+ 40.0	428 293 199	+108.5	622 997 128	+203.1

+ Increase.   − Decrease.

The above statements give the result upon the Pittsburgh, Fort Wayne and Chicago Railway, and the Pittsburgh, Chicago and St.

Louis Railway, and they show, that while on the former road, between 1873 and 1888, the engine mileage has decreased 31 per cent., the car mileage has increased 64 per cent.; the tonnage has increased 171 per cent. and the ton mileage has increased 109 per cent. On the Pittsburgh, Cincinnati and St. Louis Railway, the engine mileage during the same period has increased 21 per cent.; the car mileage has increased 83 per cent.; the tonnage increased 256 per cent.; and the ton mileage increased 203 per cent.

Similar results are obtained on all lines where the motive power capacity has been judiciously increased with the enlarged freight car capacity.

Now, of course, it would not be reasonable to expect such favorable results entirely without a sacrifice of some sort.

But this is not all. Look at the chart of rail-prices and note the reduction in cost from $120 in 1873 to $30 in 1888 for steel rail; and also glance at the price of $70 per ton for iron rail in 1873 and remember that this rail, under the much lighter wheel-loads of that time, regularly wore out in from six months to two years' time.

And then summarize the situation in 1873, and compare it with 1888. You will find that our present engines, with a greatly reduced mileage, transport much larger tonnages, that our rails cost 75 per cent. less than in 1873, and wear six times as long; so that really our condition appears satisfactory and encouraging, rather than gloomy and disheartening as Mr. Whittemore would make us believe.

Rails have been worn in the past under much lighter loads, and no doubt they will continue to wear out in the future, and so will the wheels; in fact, there is nothing upon a railroad that does not wear out; even the chief engineers, tough as they generally are, wear out in course of time.

Mr. Whittemore admits the difficulty of determining the amount of abrasion due to rolling load alone, and I agree with him fully; and I also confess that I have precious little faith in the development of a formula which gives the theoretical ton service for $\frac{1}{2}$-inch wear of wheel-tread deduced from results varying between 107 000 000 tons and 252 000 000 tons under nearly equal wheel-loads. No doubt it would seriously complicate the solution of an equation which would contain variable values for corrosion, brake shoes, sanded rails, slipping drivers, sliding wheels, abrasion by torpedoes, flow of metal, and internal strains due to imperfect manufacture; and I suggest, that the quantity remaining after deducting all these enumerated values, and which remainder would represent the legitimate wear due to the tonnage, would be anything but constant or practically reliable.

To remedy the effect of excessive loads upon the rails, Mr. Whittemore proposes to abolish coned wheels, make the rail head flat, and by increasing the contact area and bearing surface, reduce the unit pressure upon rails and wheels alike.

4°15′ Curve west of Br. 7, west bound track. OUT-
SIDE Rail. CAMBRIA, 11-'77. 60" steel.
Grade + 7.02

6° Curve west of "FORT PITT" west bound track
OUTSIDE Rail. CAMBRIA, '78. 60" steel.
Grade + 25.0
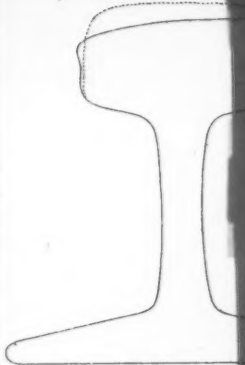
6° Curve west of "FORT PITT"
INSIDE Rail. CAMBRIA
Grade + 25.0
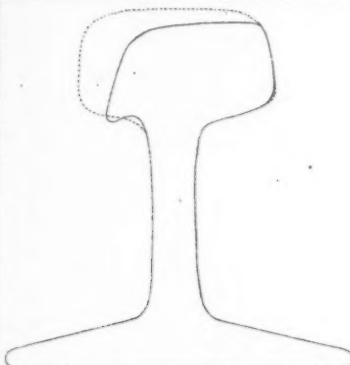
6° Curve over Br. 14, east bound track. OUTSIDE
Rail, CAMBRIA 1878. 60" steel.
Grade . 0.00
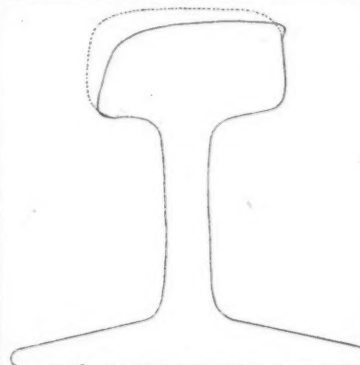
5° Curve at "OAKDALE" telegraph office. OUT-
SIDE Rail. CAMBRIA 1878. 60" steel.
Grade + 26.4.
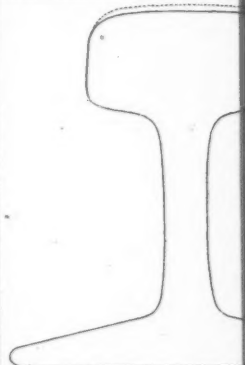
TANGENT, just east of Br. 15,
track, CAMBRIA 1878
Grade + 2. 64.
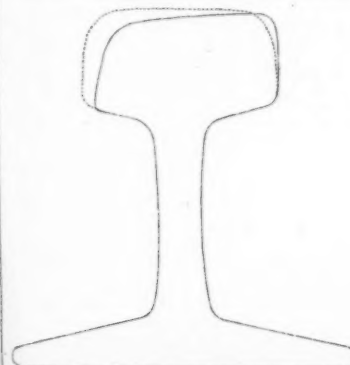
3° Curve, 1st east of "LAUREL HILL" E. bound
tk., OUTSIDE Rail. CAMBRIA 1875. 60" steel.
Grade + 5.28
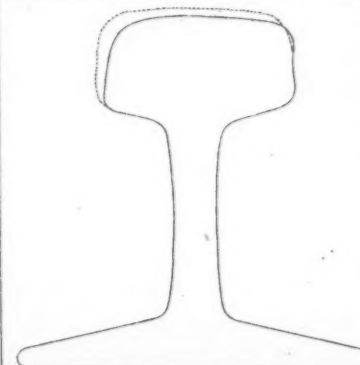
3° Curve, 1st east of "LAUREL HILL" W. bound
tk., OUTSIDE Rail. CAMBRIA 1875, 60" steel.
Grade + 5.28
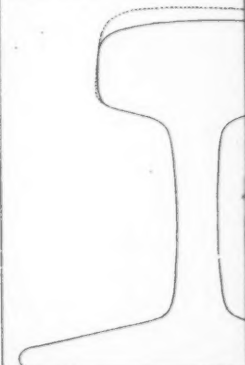
TANGENT, E. of "LAUREL
bound tk. N. Rail, CAMBRIA
Grade + 5.2

6° Curve west of "FORT PITT" west bound track.
INSIDE Rail, CAMBRIA 1878. 60ᵇ steel.
Grade ÷ 25.0
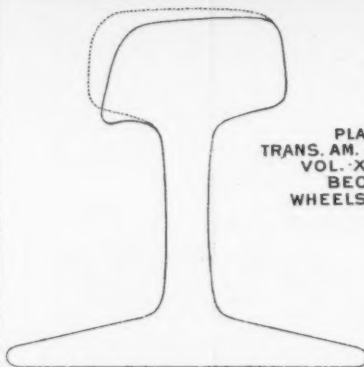
3° Curve at "WALKER'S MILL" Sta., west bound
track, OUTSIDE Rail, CAMBRIA 1878. 60
steel.
Grade + 42.24

5° Curve 1st west of Br. 14, east bound track, IN-
SIDE Rail, CAMBRIA 1878. 60ˢ steel.
Grade . 0.00.
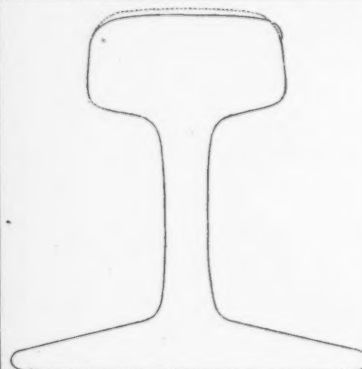
TANGENT, just east of Br. 15, S. rail, east bound
track, CAMBRIA 1878. 60ˢ steel.
Grade ÷ 2. 64.
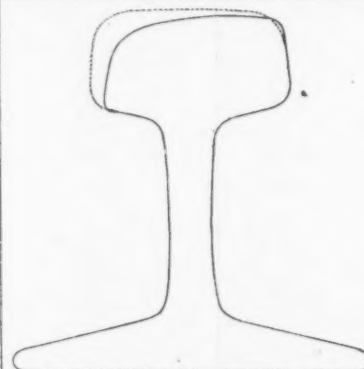
3° Curve at "NOBLESTOWN" station, W. bound
tk., OUTSIDE Rail, CAMBRIA 1878. 60ˢ steel.
Grade + 52.8
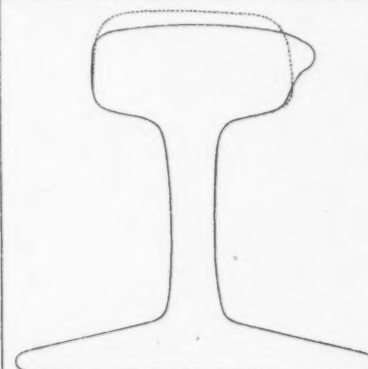
3° Curve at "NOBLESTOWN" station, E. bound
track, INSIDE Rail, CAMBRIA 1878. 60ˢ steel.
Grade + 52.8
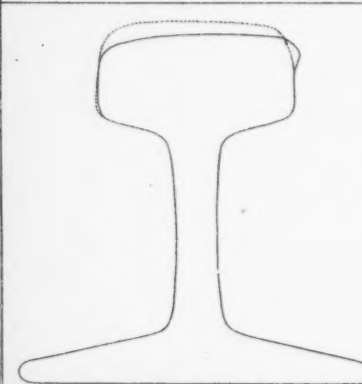
TANGENT, E. of "LAUREL HILL" mines, W.
bound tk. N. Rail, CAMBRIA 1875. 60ˢ steel.
Grade + 5.28
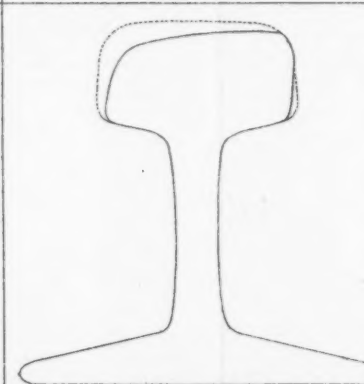
2° Curve, 1st east of "PRIMROSE" west bound
tk., OUTSIDE Rail, CAMBRIA 1875. 60ˢ steel.
Grade + 26.4
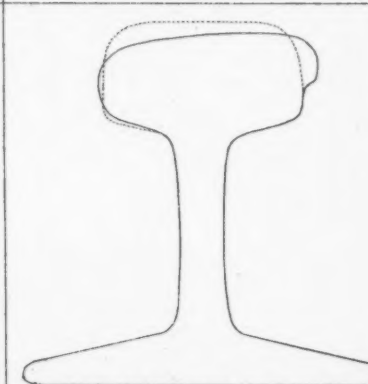
4° Curve, 2nd E. of "MIDWAY" W. bound track.
INSIDE Rail, opposite telegraph tower. "CAM-
BRIA" 1875. 60ˢ steel.
Grade + 52.8

TANGENT, 2nd E. of "MIDWAY" W. bonnd tk.,
N. Rail, CAMBRIA 1879. 60" steel.
Grade + 52.8
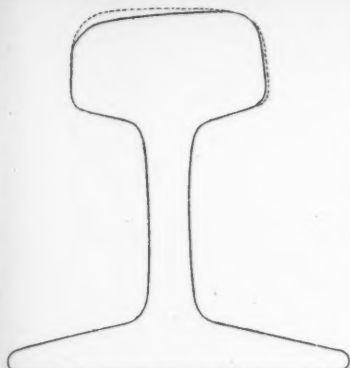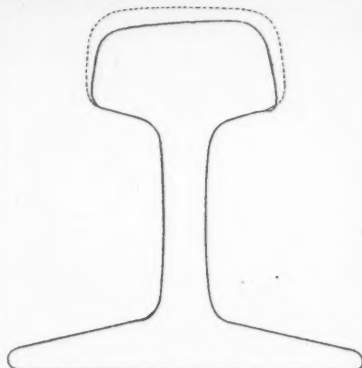
TANGENT, 2nd E. of "MIDWAY" W. bound tk.,
N. Rail, CAMBRIA 1876. 60" steel.
Grade + 52.8

TANGENT at station, "MIDW
bound tk. at Xover east of Midw
1875. 60" steel.
Grade + 52.8
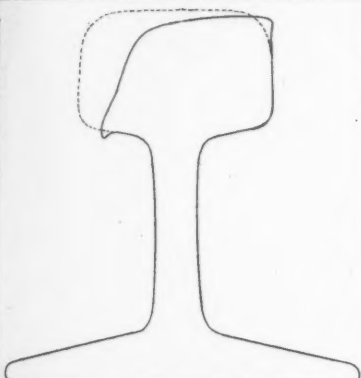
6°25' Curve, 3rd.west of "BULGER" tunnel, S.tk.
used as a single track till 12-23-'88. E.T.7-'82, OUT-
SIDE Rail, 67" steel. Grade - 52.8
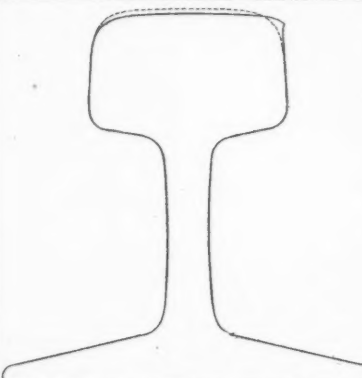
TANGENT, W. of "Springer's Dump" S. track,
used as single track till 12 23-'88. E.T.7-'82, S.Rail
67" steel. Grade - 52.8

TANGENT, W. of "Springer's D
used as single track till 12 23-'88. E
67" steel. Gra
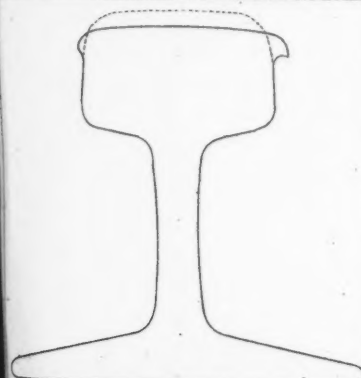
5°40' Curve, 2nd E. of "HANLIN" N. track, used
as single track till 8-2-'88, E.T.67" steel 2-'81, S.rail
Grade - 51.42
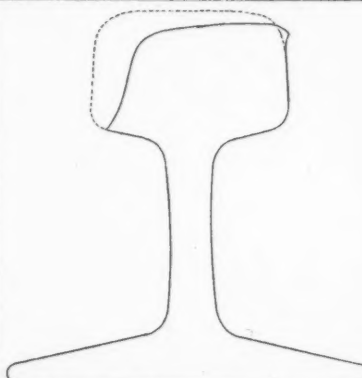
5°40' Curve, 2nd E. of "HANLIN" N. track, used
as single track till 8-2-'88, E.T.2-'81, 67" steel N.rail
Grade - 51.42
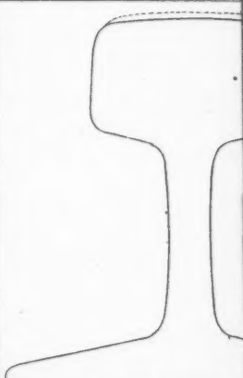
TANGENT, E. of "HANLINS"
single track until Aug. 2, '88, E.T.
rail. Grade

PLATE LVII
TRANS. AM. SOC. CIV. ENG'RS.
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BECKER ON
WHEELS AND RAILS.

TANGENT at station, "MIDWAY" S.Rail, W.
bound tk. at Xover east of Midway, CAMBRIA
1875. 60" steel.
Grade ÷ 52.8

3° Curve, 1st E. of "MIDWAY" west bound track,
OUTSIDE Rail. CAMBRIA 1875, 60" steel.
Grade + 52.8

6°25' Curve, 3rd west of "BULGER" tunnel, S.tk.,
used as single tk. till 12-23-'88, E.T.7-82, INSIDE
Rail, 67" steel. Grade – 52.8

TANGENT, W. of "Springer's Dump" S. track
used as single track till 12-23-'88. E.T.7-'82, N. Rail
67" steel. Grade – 52.8

8° Curve at W. end of "DINSMORE" tunnel, single
track, INSIDE Rail, E. T. 3-82, S. Rail. 67" steel.
Grade – 52.8

8° Curve at W. end of "DINSMORE" tunnel, single
track, OUTSIDE Rail, E.T.3-82, N. Rail. 67" steel.
Grade – 52.8

TANGENT, E. of "HANLINS" N.track, used as
single track until Aug. 2, '88, E.T. '81, 67" steel, S.
rail. Grade – 51.42

TANGENT, E. of "HANLINS" N.track, used as
single track until Aug. 2, '88, E.T.2-'88, 67" steel, N.
rail. Grade – 51.42

6°20' Curve W. of "HANLIN" station, S. tk.. used
as single tk. till Oct. '87, E.T.2-'81, 67" steel, S.rail.
Grade – 51.42
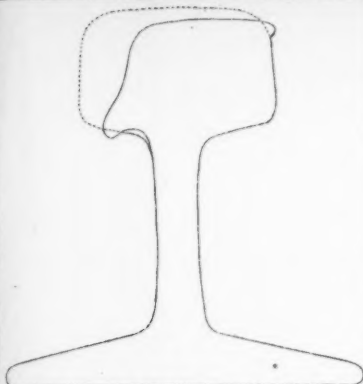
6°20' Curve W. of "HANLIN" station, S. tk., used
as single tk. till Oct. '87, E.T. 2-'81, 67" steel, N rail.
Grade - 51:42
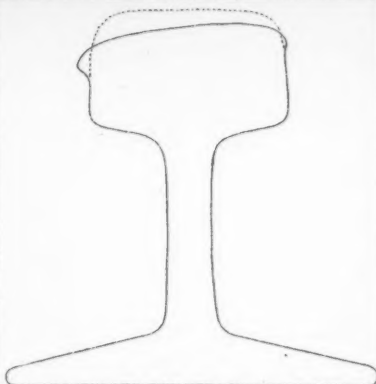
6°0' Curve, E. of Br. 18. South track., used as
single track prior to Oct. '87. E.T. 2-'81, 67" steel, S.
rail. Grade - 51.42
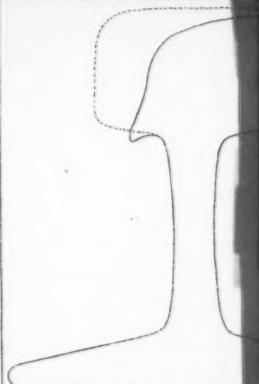
6°0' Curve, E. of Br. 18. S. or E.
single track prior to Oct. '87. E.
rail.
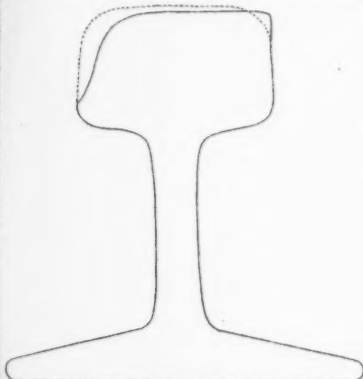
6°10' Curve E. of Br. 27, W. bound tk., used as single
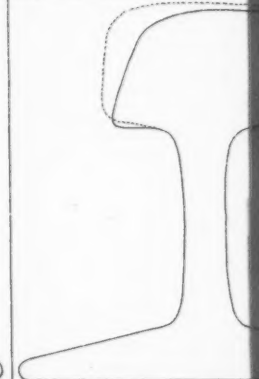tk. until Oct. '86, E.T. 7-'80, 67" steel, S. rail OUT-
SIDE rail. Grade - 32.21
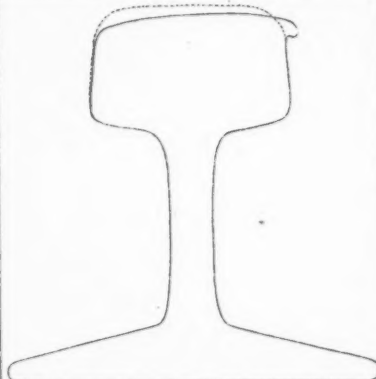
6°10' Curve, E. of Br. 27, W. bound tk., used as single
tk. until Oct. '86, E.T. 7-'80, 67" steel, N. rail IN-
SIDE rail. Grade - 32.21
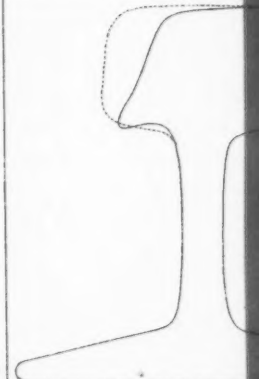
3°0' Curve, 2nd W. of "New Cum
E. bound tk, in use as single tk. u
67" steel. OUTSIDE
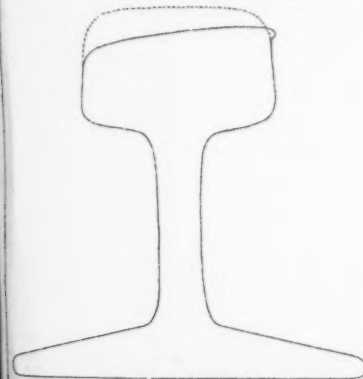
4°50' Curve, at "WHEELING JUNCTION" E.
bound tk., used as single tk. until '87 and again dur-
ing summer of '88, E.T. 7-'80, 67" steel, INSIDE
[N] rail   Grade - 42.24
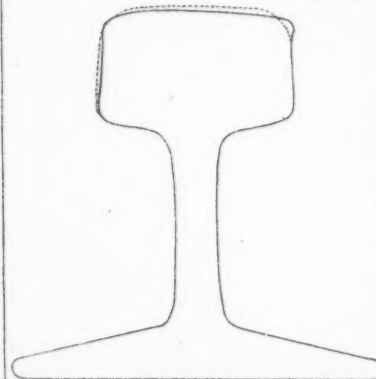
3° Curve at "IRONDALE" INSIDE rail, E.T. '83.
Grade + 11.09

3° Curve at "IRONDALE" OUT
Grade + 11.

PLATE LVIII.
TRANS. AM. SOC. CIV. ENG'RS.
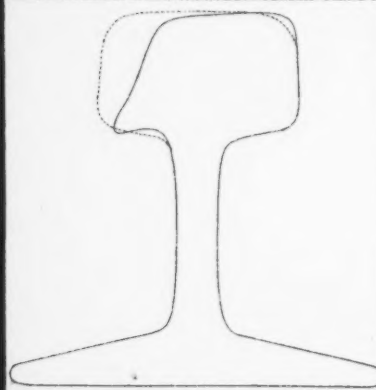VOL. XXI. Nº 424.
BECKER ON
WHEELS AND RAILS.
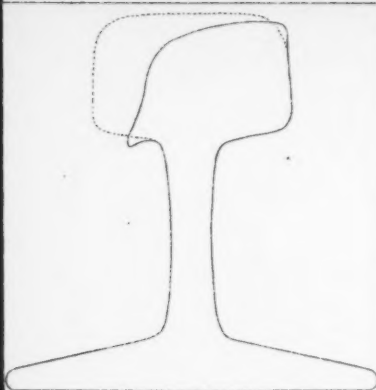
6°0' Curve, E. of Br: 18. S.or E.bound tk., used as single track prior to Oct. '87. E.T.2-'81, 67ª steel, N. rail.   Grade - 51.42
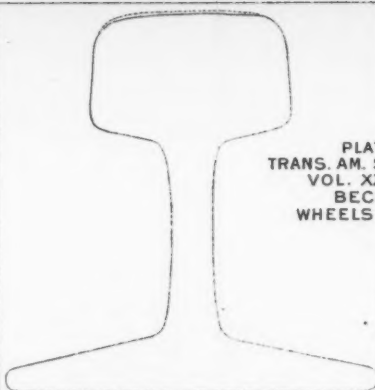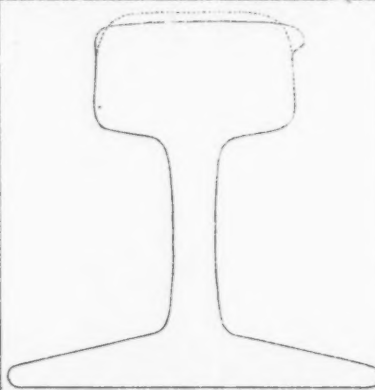
Long Tangent, 2m W. of "Colliers" W. bound track. used as single track until Oct. '86, E.T.7-'80 67ª'steel S. rail.   Grade - 32.21
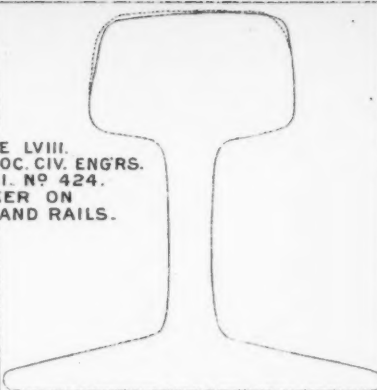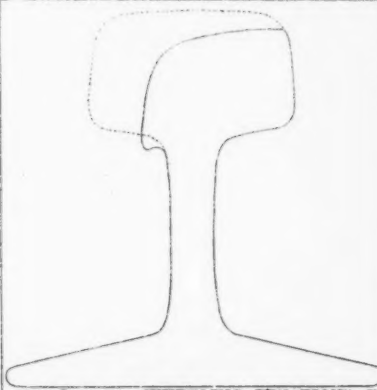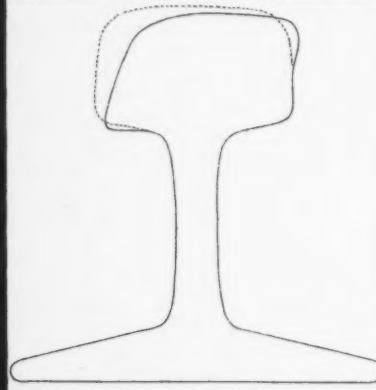
Long Tangent, 2m W. of "Colliers" W. bound track. used as single track until Oct. '86, E.T.7-'80 67ª'steel S. rail.   Grade - 32.21

3°0' Curve, 2nd W. of "New Cumberland Junction" E.bound tk, in use as single tk. until 1887, E.T.7-'80 67ª steel. OUTSIDE [S] rail   Grade + 42.24
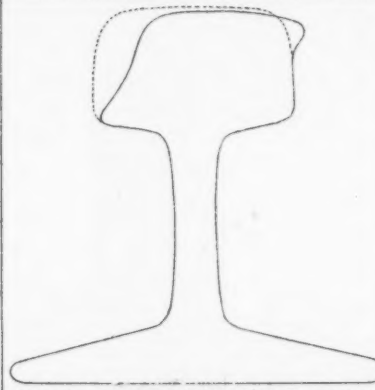
3°0' Curve, 2nd W. of "New Cumberland Junction" E.bound tk, in use as single tk. until 1887, E.T.7-'80 67ª steel, INSIDE [N] rail.   Grade + 42.24
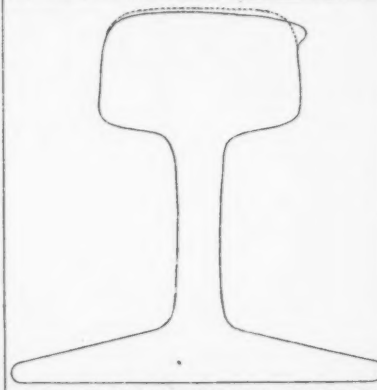
5°50' Curve at "WHEELING JUNCTION" E. bound tk., used as single tk. until '87 and again during summer of '88, E.T. 7-'80, 67ª steel, OUTSIDE [S] rail   Grade + 42.24

3° Curve at "IRONDALE" OUTSIDE rail, E.T. '83
Grade + 11.09

About 12m E. of "FERNWOOD" 2°0' Curve to left. E.T.'83 OUTSIDE Rail.
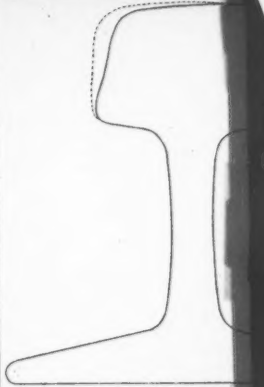Grade + 11.09

2° Curve 1st E.of "FERNWOOD" INSIDE Rail, E.T.'83
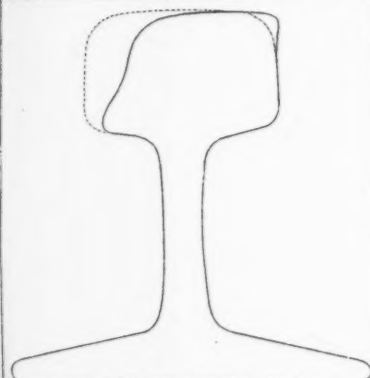Grade + 11.09

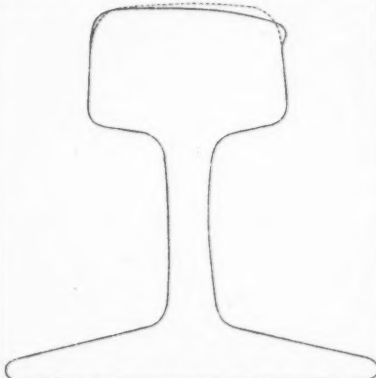2° Curve, 1st east of FERNWOOD OUTER Rail
E.T. '83. 67° steel.
Grade + 13.73

TANGENT E. of FERNWOOD S.rail, E.T. '83
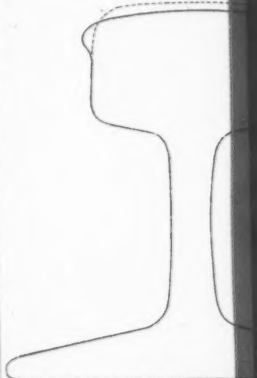67° steel.
Grade + 13.73

2° at FERNWOOD OUTER
67° steel.
Grade + 13.73

3° Curve, 1st E. of No. 6 TUNNEL, OUTSIDE
Rail, E.T. '83, 67° steel.
Grade + 39.6

3° Curve, 1st E. of No. 6 TUNNEL, INSIDE
Rail, E.T. '83, 67° steel.
Grade + 21.12

3° Curve over Br. 39, INSIDE
67° steel.
Grade .. 0.00
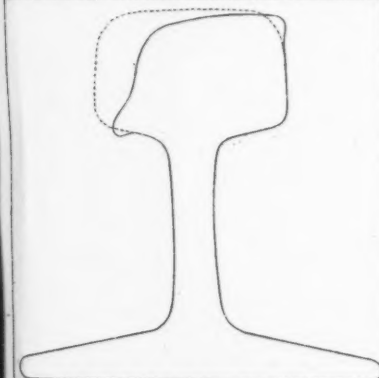
3° Curve east of Br. 41, OUTSIDE Rail, E.T. '82.
67° steel.
Grade . 0.00

2° Curve, 1st. east of SKELLEY'S, INSIDE Rail,
E.T. '82, 67° steel.
Grade + 15.34

2° Curve, 1st, east of SKELLEY
E.T. '82, 67° steel.
Grade + 1

PLATE LIX.
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WHEELS AND RAILS.
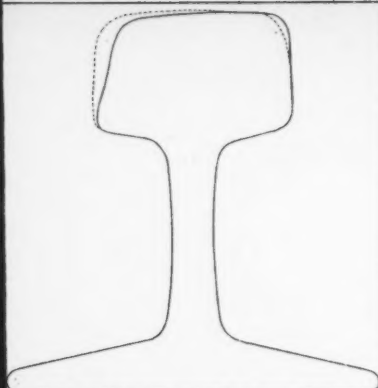
2° at FERNWOOD OUTER rail, E.T. '83,
67ª steel.
Grade + 13.73
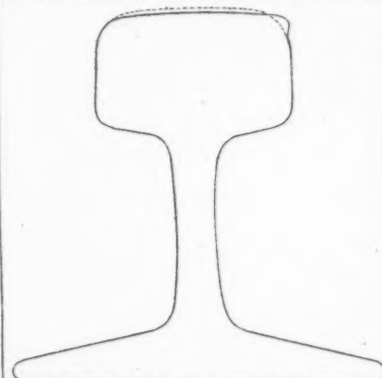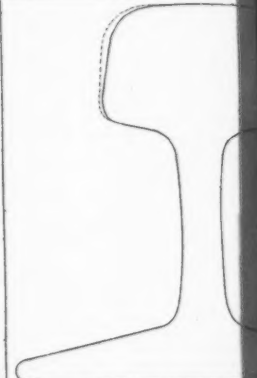
2° Curve at FERNWOOD INSIDE rail, E.T. '83
67ª steel.
Grade + 13.73
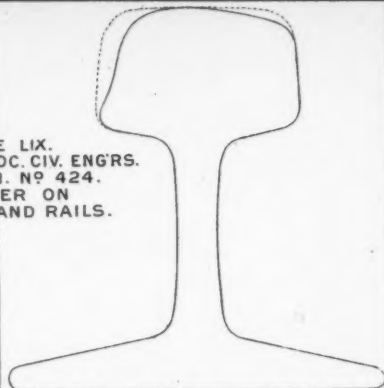
3° Curve 1st east of Br. 36, OUTER rail, E.T. '83,
67ª steel.
Grade + 39.6
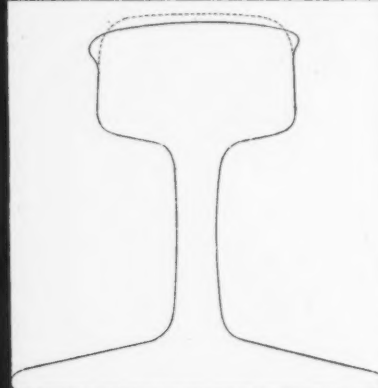
3° Curve over Br. 39, INSIDE Rail, E.T. '82,
67ª steel.
Grade - 0.00
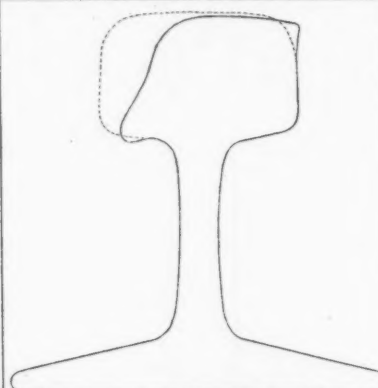
3° Curve over Br. 39, OUTSIDE Rail, E.T. '82.
67ª steel.
Grade - 0.00

3° Curve east of Br. 41, INSIDE Rail, E.T. '82,
67ª steel.
Grade - 0.00

2° Curve, 1st, east of SKELLEY'S, OUTSIDE Rail,
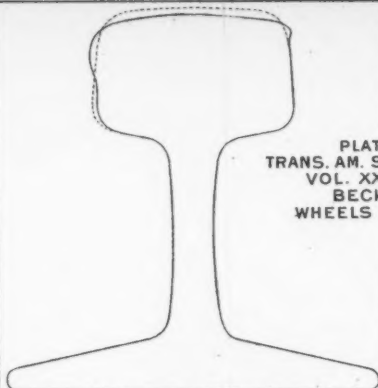E.T. '82, 67ª steel.
Grade + 15.34

1st TANGENT E. of "SKELLEY'S," N. Rail, E.T.
'82, 67ª steel.
Grade + 39.60
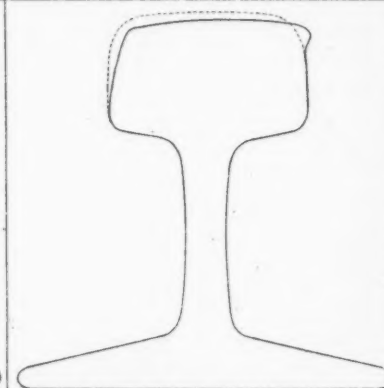
TANGENT, east of No. 7 Tunnel, CAMBRIA.
'81. 67ª steel.
Grade + 39.60
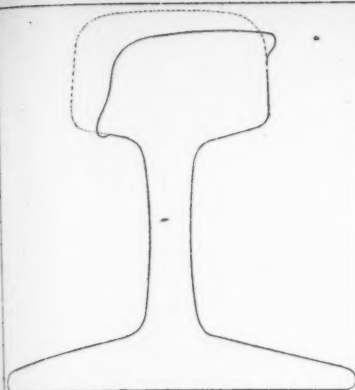
3° Curve at Br. 43, OUTSIDE Rail, CAMBRIA '81, 67ᵃ steel. Grade + 13.2
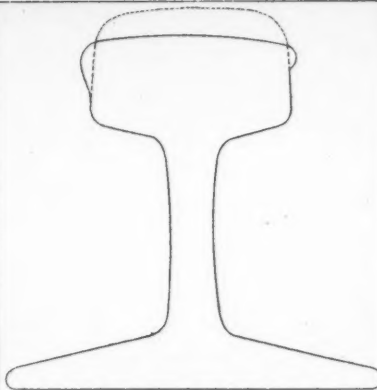
3° Curve at Br. 43, INSIDE Rail, CAMBRIA '81; 67ᵃ steel. Grade + 13.2
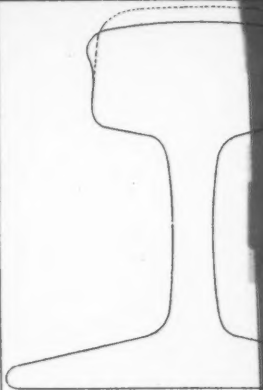
3° Curve, at "BLOOMFIELD" CAMBRIA, '81, 67ᵃ Grade + 39.6
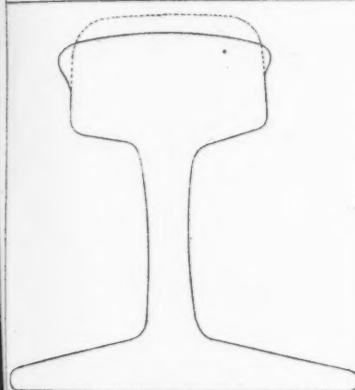
2°14' Curve 1st east of Br. 44, INSIDE Rail, CAMBRIA '81, 67 steel. Grade + 39.6
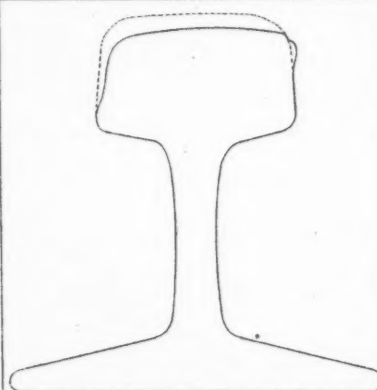
TANGENT, east of No. 8 Tunnel, S.Rail, CAMBRIA '81, 67ᵃ steel. Grade + 39.6
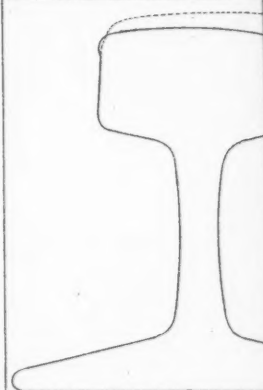
Between Br. 45 and No. 8 Tunnel, CAMBRIA '81, 67ᵃ steel, 3° Grade + 39.6
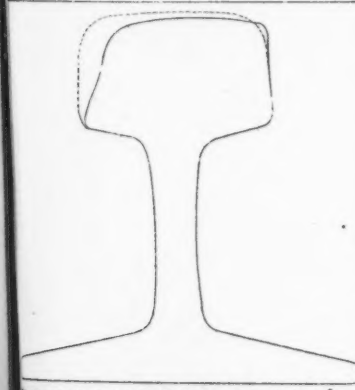
3° Curve Br. 45, OUTSIDE Rail, E.T. 11-'82, 67 steel Grade + 39.6
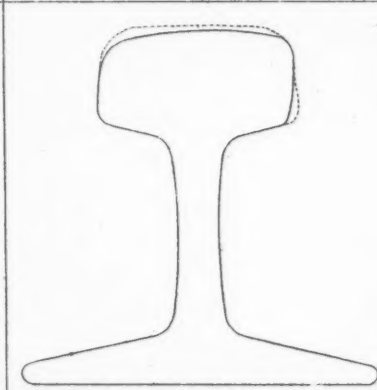
TANGENT, at "CONOTTON" N. Rail, E.T. '76 60ᵃ steel. Grade - 3.17
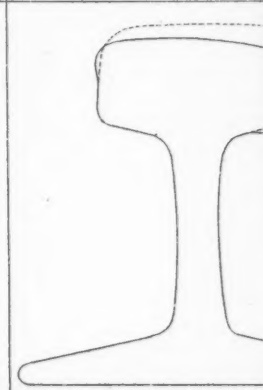
3° Curve, 1st W. of "CONOTTON" IN E.T. '76, 60ᵃ steel. Grade - 3.17

PLATE LX.
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WHEELS AND RAILS.
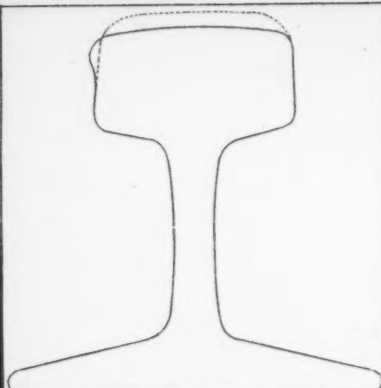
3° Curve, at "BLOOMFIELD" INSIDE Rail,
CAMBRIA, '81. 67' steel.
Grade + 39.6
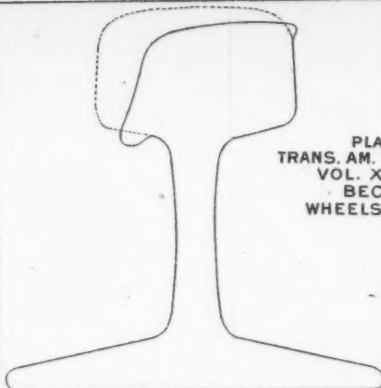
3° Curve, at "BLOOMFIELD" OUTSIDE Rail,
CAMBRIA, '81. 67' steel.
Grade + 39.6
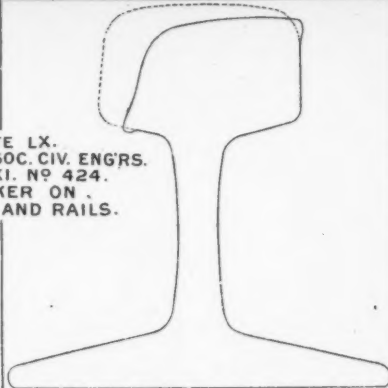
2° 14' Curve; 1st east of Br. 44, OUTSIDE Rail,
CAMBRIA '81, 67' steel.
Grade + 39.6
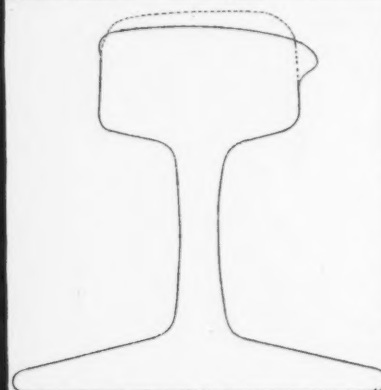
Between Br. 45 and No. 8 Tunnel. INSIDE Rail.
CAMBRIA '81, 67' steel, 3° Curve.
Grade + 39.6
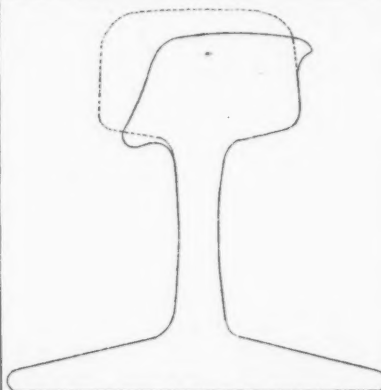
Between Br. 45 and No. 8 Tunnel. OUTSIDE Rail.
CAMBRIA '81, 67' steel, 3° Curve.
Grade + 39.6
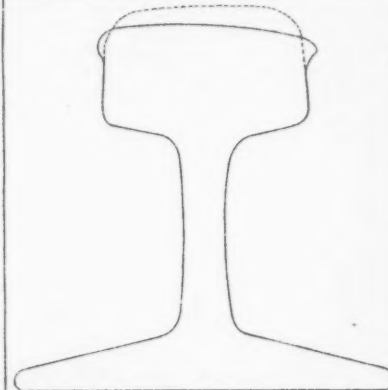
Between Br. 45 and No. 8 Tunnel. INSIDE Rail,
E.T. 11-'82, 67' steel, 3° Curve.
Grade + 39.6
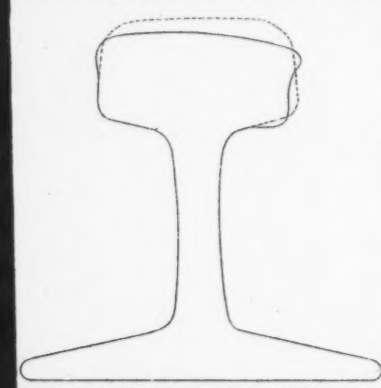
3° Curve; 1st.W. of "CONOTTON" INSIDE Rail
E.T. '76, 60' steel.
Grade - 3.17
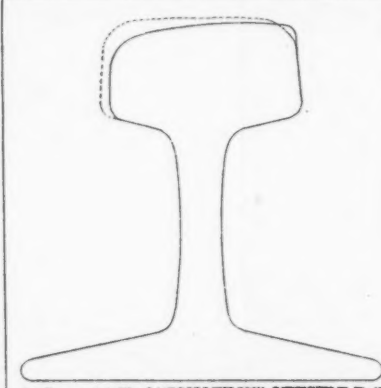
3° Curve, 1st.W. of "CONOTTON" OUTSIDE Rail
E.T. '76, 60' steel.
Grade - 3.17
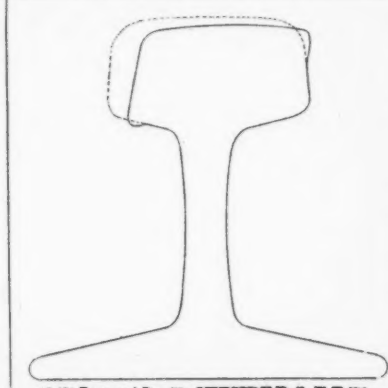
1° 40' Curve at Br. 59, OUTSIDE Rail, E.T. '76,
60' steel.
Grade + 39.6.
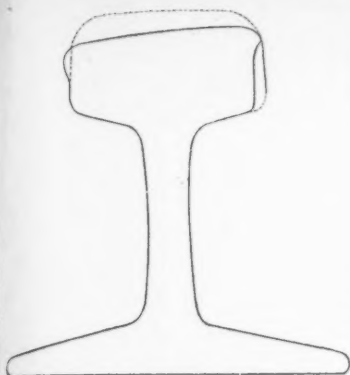
1°40' Curve at Br. 59, INSIDE Rail, E.T.'76,
60'steel.
Grade + 39.6
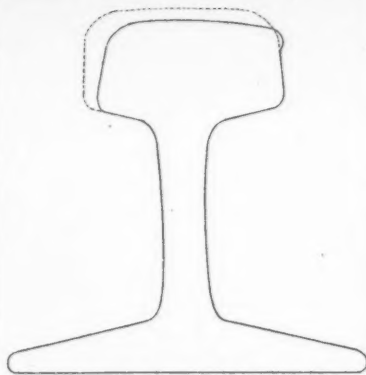
1° Curve at "BOWERSTOWN" OUTSIDE Rail,
E.T.'76, 60' steel.
Grade + 39.6
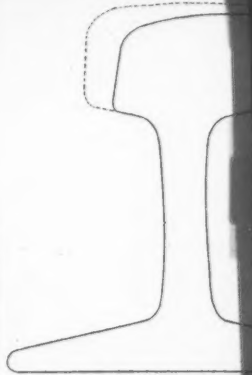
2° Curve; 3rd E of "PHILADEL
OUTSIDE Rail, E.T.'76,
Grade - 39.6

2° Curve; 3rd E of "PHILADELPHIA ROAD"
INSIDE Rail, E.T.'76, 60° steel.
Grade - 39.6
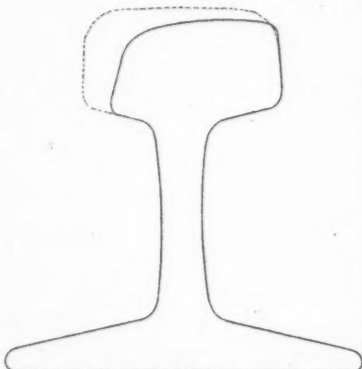
2° Curve; 1st W, of M. P. '87, OUTSIDE Rail, E.
T.'76, 60° steel.
Grade - 39.6
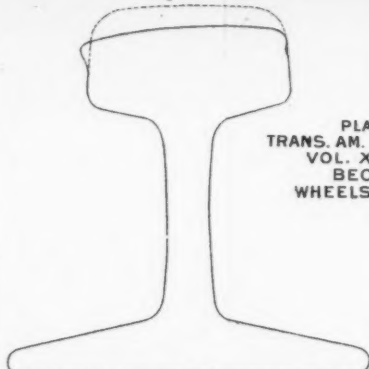
1° Curve; about 6m E.of "PHIL
ROAD" INSIDE Rail, E.T
Grade - 39.6

PLATE LXI
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BECKER ON
WHEELS AND RAILS
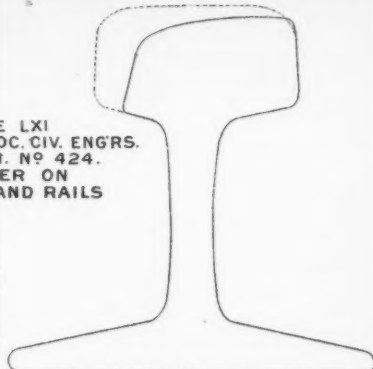
2° Curve; 3rd E of "PHILADELPHIA ROAD"
OUTSIDE Rail. E.T.'76, 60° steel.
Grade - 39.6

2° Curve; 3rd E of "PHILADELPHIA ROAD"
INSIDE Rail. E.T.'76, 60° steel.
Grade - 39.6

2° Curve; 3rd E. of "PHILADELPHIA ROAD"
OUTSIDE Rail. E.T.'76, 60° steel.
Grade - 39.6
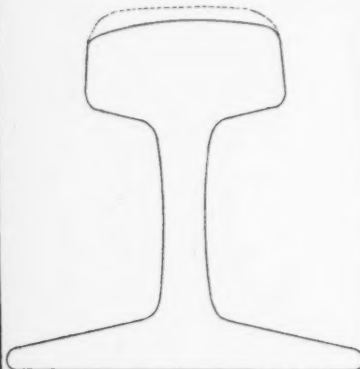
1° Curve; about 6m E of "PHILADELPHIA
ROAD" INSIDE Rail. E.T.'76, 60° steel.
Grade - 39.6
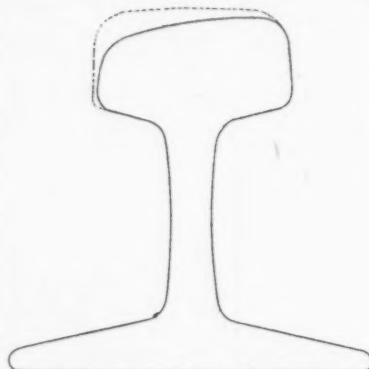
2° Curve; 1st East of "PHILADELPHIA
ROAD" OUTSIDE Rail. E.T.'76, 60° steel.
Grade - 39.6
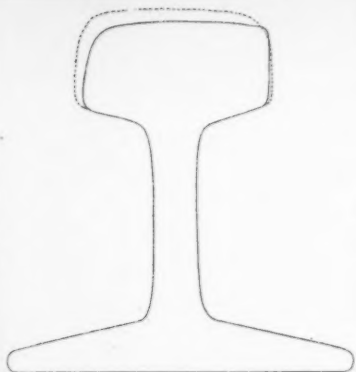
East of 'UHRICHSVILLE JUNCTION' E bound
track, "CAMBRIA" 1876, TANGENT, 60 ° steel.
Grade 0.00.
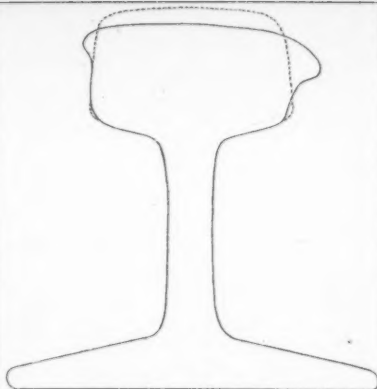
INSIDE Rail on 3° Curve, 1st Curve E. "TREN-
TON" E.bound tk, near Joint, E.T.1883, 67 steel.
Grade - 36.96

. OUTSIDE Rail on 3° Cur
"TRENTON" E.bound tr
Grade

INSIDE Rail on 1° Curve, "GLASGOW" N. Rail,
at Joint, CAMBRIA '78. 60 ° steel.
Grade - 1.58

OUTSIDE Rail on 1° Curve, "GLASGOW" S.rail
CAMBRIA '78, 60 ° steel,
Grade - 1.58
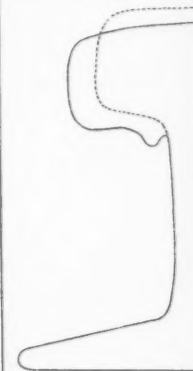
INSIDE Rail on 1° Curve
joint, tie mashed, CAMBRI
Grade

TANGENT, near E. Sw. "New Comerstown" N.
rail. CAMBRIA '78, 60 ° steel.
Grade - 4.22.
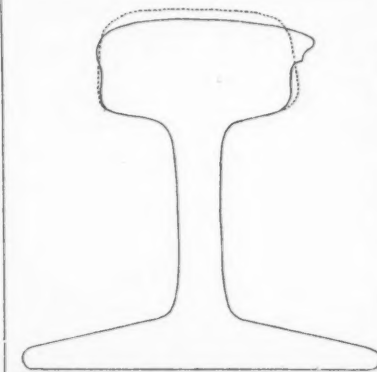
TANGENT, near E. Sw. "New Comerstown" S.
rail. CAMBRIA '78. 60 ° steel.
Grade - 4.22.

Section of beat rail near E S
TANGENT, S. rail, CAM
Grade

OUTSIDE Rail on 3º Curve, 1st Curve east of "TRENTON" E.bound track, E.T.1883, 67"steel.
Grade – 36.96
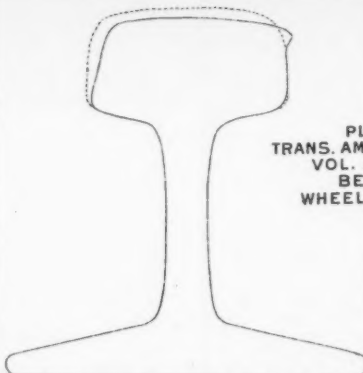
South side, main track, 1m.W. of "PORT WASH- INGTON" TANGENT, CAMBRIA '78, 60"steel.
Grade – 2.64
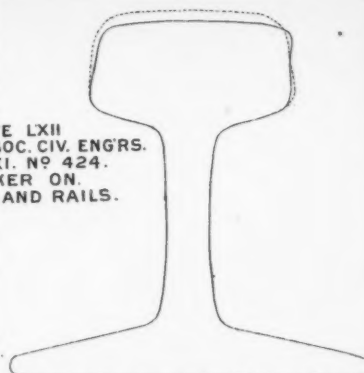
North Rail, main track, 1m.W. of "PORT WASH- INGTON" TANGENT, CAMBRIA '78, 60"steel
Grade – 2.64

INSIDE Rail on 1º Curve, "GLASGOW" near joint, tie mashed, CAMBRIA '78, 60"steel, N.rail
Grade – 1.58

OUTSIDE Rail on 1º Curve, "GLASGOW"S.Rail. CAMBRIA '78. 60"steel.
Grade – 1.58

North [INSIDE] rail on Curve [1º] at "GLAS- GOW" CAMBRIA '' '78, 60"steel.
Grade – 1.58

Section of best rail near E Sw. "New Comerstown" TANGENT, S. rail, CAMBRIA '78, 60"steel,
Grade – 4.22.
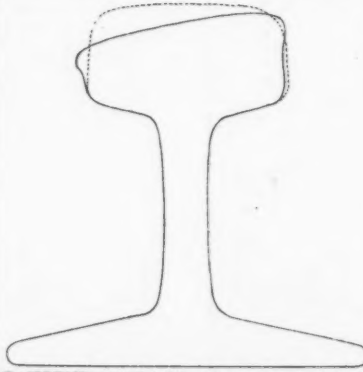
TANGENT opposite "New Comerstown" station, N.rail, CAMBRIA '78, 60"steel.
Grade – 4.22.
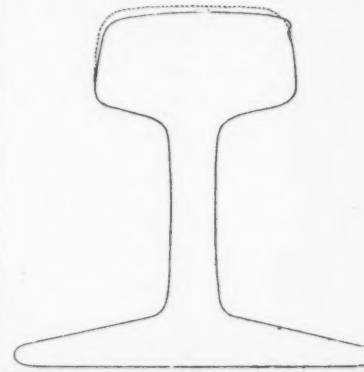
TANGENT, N.rail, E.of "WEST LAFAYETTE" station, CAMBRIA '77, 60"steel,
Grade . 0.00
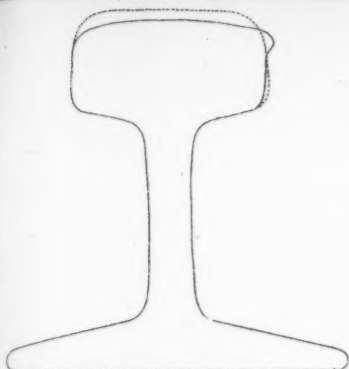
TANGENT, East of "MORGAN RUN" S.rail
CAMBRIA '77. 60 steel.
Grade - 2.64
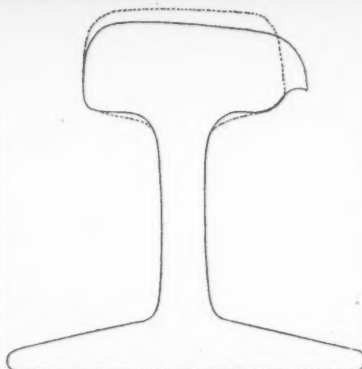
TANGENT, East of "MORGAN RUN" N.rail
at Joint, CAMBRIA '77. 60 steel.
Grade - 2.64

TANGENT, East of "MORGA...
at Joint, CAMBRIA '7...
Grade - 2.64
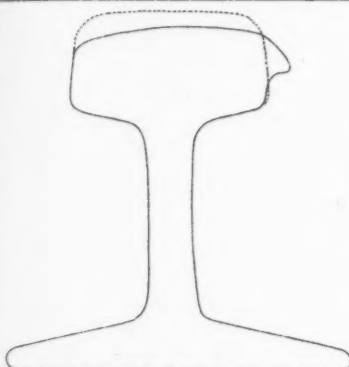
INSIDE Rail, on 0°30' Curve, "ADAMS' MILL,
N.rail. CAMBRIA '77, 60 steel.
Grade. 0.00
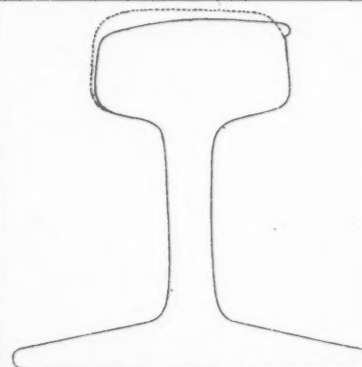
South rail on TANGENT, 1m. E. of "DRESDEN
JUNC." CAMBRIA '77, 60 steel.
Grade - 0.528

South rail on TANGENT, 1m. W...
JUNC." E.T.'75, 60...
Grade - 0.528

South Rail on TANGENT, 1m. W. of "WAKA-
TOMIKA" CAMBRIA '77. 60 steel.
Grade. 39.5 -
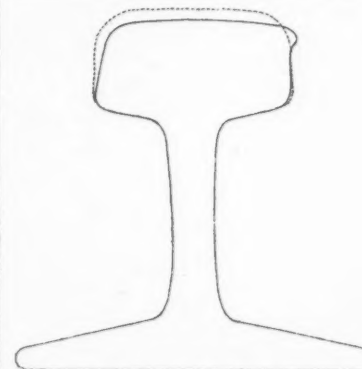
North Rail on TANGENT, west of "FRAZEYS-
BURG" telegraph office, CAMBRIA '77, 60 steel.
Grade. 0.00
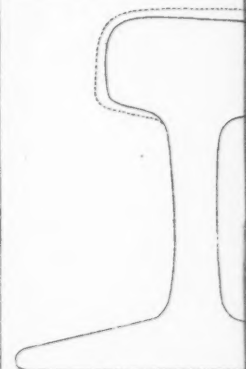
North Rail on TANGENT, near ...
RUN," CAMBRIA '7...
Grade. 0.00

TANGENT, East of "MORGAN RUN" N. rail at Joint. CAMBRIA '77. 60' steel. Grade - 2.64

0°30' Curve, INSIDE rail at Joint, "ADAMS" MILL" N. Rail, CAMBRIA 1877, 60' steel. Grade. 0.00

PLATE LXIII.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XXI. N° 424.
BECKER ON
WHEELS AND RAILS.
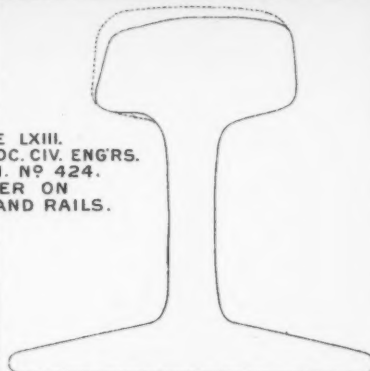
0°30' Curve, OUTSIDE rail "ADAMS" MILL" S. Rail, CAMBRIA '77. 60' steel. Grade. 0.00
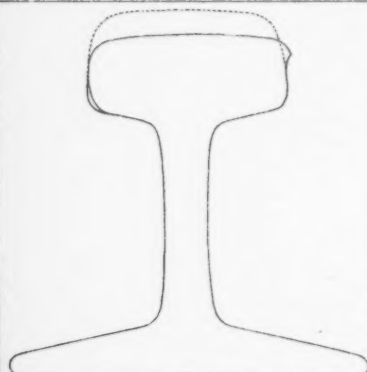
South rail on TANGENT, 1m. W. of "DRESDEN JUNC." E.T. '75. 60' steel. Grade - 0.528
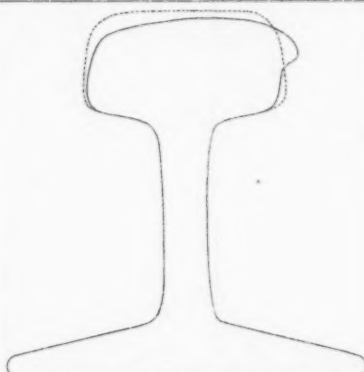
North rail on TANGENT, 1m. E. of "DRESDEN JUNC." CAMBRIA '77, 60' steel. Grade - 0.528
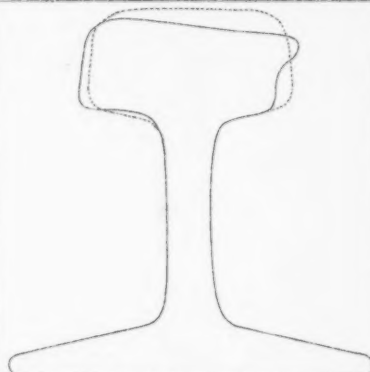
North rail on TANGENT, 1m. W. of "DRESDEN JUNC." CAMBRIA '77, 60' steel. Grade - 0.528
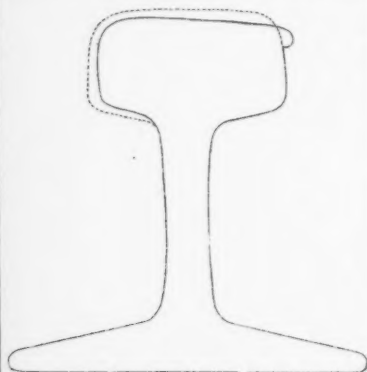
North Rail on TANGENT, near E. Sw. at "BLACK RUN," CAMBRIA '77, 60' steel. Grade. 0.00

If this would satisfactorily accomplish the purpose, it certainly ought to be done; but I would apprehend that the wheels would not maintain their perfectly cylindrical shape, nor the rails preserve their flat horizontal heads after a short period of actual use.   Between the track gauge and the wheel gauge there is a difference of ⅜ of an inch, which admits of a continuous oscillation corresponding to that space, and unless the wheels can be made of a metal wholly indestructible, a curved groove will be worn into their treads in course of time, which will either cause the wheels to run upon the outer edges of the flat rail head, and thereby abrade the corners; or, more likely, will wear the entire rail head to a curve corresponding to the groove in the tread.

I attach hereto prints of 112 rail sections (see Plates LVI–LXIII), carefully measured at various places in our tracks between Pittsburgh and Columbus, showing the sizes and conditions of the rails, and if any lesson is to be learned from this exhibit, it is to the effect, that under ordinarily favorable conditions, the rails wear reasonably well; upon sharp curves they naturally wear faster; a slight flow or spreading of the metal is indicated upon the outer edges of the rails.   No doubt the same flow occurs on the inner edges as well, but is constantly ground off by the wheel flanges; but this flow does not, in my opinion, hasten the destruction of the rails to any marked extent; they fail upon tangents from vertical wear and upon curves by the abrasion of the inner sides of the heads.   As long as this kind of wear continues uniform, there can be no special cause for complaint.   It is the irregular destruction of individual rails from defective manufacture which gives just cause for dissatisfaction and alarm.

These defects have been very clearly pointed out by Mr. R. W. Hunt, by Mr. Mattes, and by Mr. Hawks; their causes are being generally understood and admitted and the remedies will no doubt be promptly applied.   Wider and shallower heads with flatter tops and sharper corners will avoid the defects caused by internal strains due to injudicious distribution of metal, and afford greater resistance against wheel pressure.

While we are engaged in these efforts of reforming the rail sections, we should begin by reducing the endless variety of patterns to a few standards of normal shape; this would not only save much outlay to the manufacturer in making new rolls and constantly changing them for every trifling order, but would avoid much confusion and simplify the labors of all concerned.   The catalogue of the Cambria Iron Company alone contains forty-five different patterns for sixteen different weights. The 60-pound pattern alone has seventeen different shapes.   Of all these numbers there must be one that is better than all the rest, and if we can determine which one it is, by all means let us have it.

D. J. WHITTEMORE, Past President Am. Soc. C. E.—In partial answer to the discussion of the author's paper on " Cylindrical Wheels and Flat

Topped Rails " by our worthy President, I feel impelled to say that his deductions fortify me in the statement I made that "car wheels and rails to the value of nearly a billion of dollars pass into the scrap heap every few years on this continent alone." It was this fact that in the main prompted me to dictate my paper.

By the words "every few years" my evident meaning was to embrace in this period their service as wheels and rails before they went to the scrap heap, be the same five or fifteen years. At the time my paper was written wheels and rails were worth $30 per ton in Chicago, and this would make the value of wheels and rails on this continent, as estimated by our President, $975 000 000, approximating closely to the author's statement. I did not endeavor to show annual depreciation or the value of the scrap heap, but left that for each member to infer what it was as his judgment might warrant. This the honorable President has done in a manner satisfactory to himself; whether it be so to our members remains for them to determine.

The author is pleased to learn that our President advocates wider heads and flatter top.

I have no doubt that the President will agree with me that many of our rails of forty years ago had a top of from 4 to 5 inches radius. When they were worn out this curve approximated a radius of 6 inches, many of the second generation of rails were then formed with a 6-inch radius, the third came out of the track having a radius of 8 inches, the fourth with about ten, and now the fifth is generally designed with a 12-inch radius. Many exceptions, of course, can be cited, but this has been the general rule. By referring to the diagrams of tangent rail wear contained in the Preliminary Report of the Committee on the relation of wheels and rails to each other, it will be seen that the average radius of worn rail tops of the Pennsylvania Railway have been beaten down from a radius of not more than 12 inches to over 14. Do these facts mean anything? With the constant tendency to flatten tops, why not make it flat at once, and then demonstrate whether a large portion of the rail head will remain so or not?

The amplitude of the oscillation of wheels and rails will, of course, demand corner curves, and it is plain to see that these curves will be of a spiral nature, as is well shown by the diagrams I have above cited, and which curve can be approximately described by commencing about $\frac{4}{10}$ths of an inch from the perpendicular of the side of rail with a curve of $\frac{3}{4}$-inch radius extending through 12 or 15 degrees, thence compounding to a curve of $\frac{1}{4}$-inch radius, through the balance to the perpendicular.

Of course, with wheel-treads already worn hollow on round-headed rails, the change to a flat head, and to maintain it practically flat, becomes difficult, but not in my opinion entirely impracticable in time through general adoption.

In regard to tire wear, our President evidently attaches but little or

no value to the facts the author presents. That it is reasonable to suppose the material in steel tires may vary somewhat, as to its elastic limit, as is shown to be the case in rails, may well account for the great variation they give in tonnage service, but it seems to the author that the general averages he gives are worthy of consideration in support of the opinion he advances. Many of the sections of rails shown by the President indicate, and he unqualifiedly admits, flow of metal, the sure indication that the elastic limit is exceeded. In what other device does he or we attempt to subject metal to such strains, and if it is not proper, how can a change of practice be effected, presupposing, of course, that the wheel-loads will never be less than they are now.

Again, some of the wheels referred to in the table were undoubtedly such as had never been subject to brake-wear, as, for instance, the middle wheels of a six-wheel truck; and this fact may well account for varying results—upon which our President says he has precious little faith in the development of the author's formula giving the theoretical tonnage service of wheels.

In answer I desire to say that the formula is purely an arithmetical one, not empirical in any sense of the word, and while I believe I am the first to express wheel wear on a tonnage basis, I also feel prepared to say that the formula is as correct as that which is used to ascertain the tonnage service of rails. I presume, however, that the President means to take exceptions to the determinations derived from the formula, that the same are such as to leave him but precious little faith as to their value.

It is strange how differently we esteem these values and determinations. My argument is that the table in question shows that wheels running at or near the limit of elasticity and at the same time subject to the contingent wear from brake-shoes, slipping, etc., give us a tonnage service, for a wear of one-eighth of an inch, of from two and one-half to six and one-half times the tonnage service we secure from the two parallel rails of good quality as now designed, before they go to the scrap heap.

The decreased engine mileage compared with car mileage, which is cited, is directly attributable to heavy engine service, resulting in wonderfully decreased cost of transportation. There is no question about this. From this cause and fierce rival interest combined, lower rates have prevailed, dividends to stockholders are less, or are passed, and managers are now demanding of the engineer how this economy of train service can be perpetuated. To this end much will be accomplished when the rapid deterioration of rail is prevented.

In this connection we should bear in mind that from thirty to sixty overloaded freight car wheels pass over our rails to one engine-driver, hence the injury to rails can be attributed largely to freight service ; our

permitted loads on freight wheels being about double that of English and French practice.

A. M. WELLINGTON, M. Am. Soc. C. E.—I have listened with very great interest and instruction to the paper by Mr. Whittemore. In regard to one subject I think that there can be no doubt that he is correct; that is, the enormous disproportion between the rail wear caused by the tires of the locomotives and by car wheels. According to the best available evidence, something like three-fourths of the rail wear results from the locomotive and only one-fourth from the much larger tonnage of the cars. That has been heretofore an unproven hypothesis, because it can only be determined in an indirect way; but the data which Mr. Whittemore has collated is exactly in accordance with what engineers who have studied the matter have concluded on that subject.

One point of difficulty that has occurred to me, among others, in listening to the paper, leads me to feel considerable doubts as to Mr. Whittemore's conclusions, viz.: the modulus of elasticity in a mass of metal loaded in the center by a weight which does not extend over its entire surface. I have myself, with a view of determining whether there was any permanent set from the locomotive, arranged to have a locomotive, the heaviest I could get, run over some rails and to be left there as long as possible. Now, if the quick passage of a locomotive over a rail produces permanent set, it seems logical that one whose weight continued to rest on one spot for from one hundred to two hundred hours would produce still more permanent set; but the most careful effort to find some sign of indentation failed. If it is true that the weight of a locomotive, in quickly passing over, produces in the rail large permanent set, then standing on the rail from a day to a week should produce more permanent set, sufficient at least to be detected by the reflection of a ray of light; but such is not the case.

On the other hand, it is entirely feasible to explain that there is, from a locomotive running at speed, a great deal of rubbing friction; from lateral motion or the lurching of the train from one side to the other, as also from unequal diameters of wheels, etc. I think it has been practically proven by comparison with the wear which takes place on curves and on tangents, that all the tangent wear that occurs can be accounted for as caused by abrasion only. If it were true that the instantaneously applied weights produced permanent set, some of our rails which stand a great many such loads a minute would be worn away and could not stand for any length of time, whereas some rails do last fifteen or twenty years.

Mr. WHITTEMORE.—In my investigations of this subject some twelve years ago, I did not have the benefit of Dr. Grashof's analysis; but pursuing nearly the same method of reasoning that he does, I arrived at nearly the same results as his formulas give. From the area of the con-

tact of a 70-inch tire under a load of from 13 000 to 16 000 pounds, the compression of both tire and rail combined did not show over about $\frac{2}{1000}$ of an inch; but.the more I have thought of the matter, the more I am convinced that the material of rail and wheel were pressed to beyond their elastic limit.

Relative to the modulus of elasticity used in the application of Dr. Grashof's formula, I wish to remark that the greatest variation we can allow from the knowledge we have, when applied to the rails of which tests are given, will be between 27 000 000 and 31 000 000, and by taking either one of these values, but little difference will be found in the results given in my table.

Mr. WELLINGTON.—Has Mr. Whittemore ever made the experiment of taking a block of Bessemer steel, planing it off flat, and then taking a smaller rounded block, like the tread of a wheel, and applying successive pressures to it until a permanent set is produced, and then determining what pressure per square inch was necessary to produce it?

Mr. WHITTEMORE.—I have not made such tests.

Mr. WELLINGTON.—In questions of such moment it seems to me that we cannot rely on mathematical analysis for conclusions; we all know how liable purely mathematical analyses are to fail under test. We can deduce general results from specific experiments by their aid, but it is somewhat unsafe, if the formulas do not rest on experiment, to attempt any generalization on their evidence alone. Do Professor Grashof's deductions rest on experiment?

Mr. WHITTEMORE.—Dr. Grashof distinctly says the modulus of elasticity and of resistance must be first determined by experiment, and this having been determined, his formulas apply to their several cases. In the absence of these values, I have applied moduli as usually determined, as the best testimony we can offer in the absence of further tests.

I wish to say a word in regard to aluminum. The refined analysis of steel given in my paper shows that it contains $\frac{1}{1000}$ per cent. of that metal, and if at moderate cost we can add about nine times this amount, it would be of great advantage, provided its benefit is anything like what is claimed for alloys of that kind. I feel sure that aluminum steels of this grade can be furnished for from $5 to $6 per ton over the price of steel, in the belief that we will soon be able to supply aluminum for $3 or a trifle less per pound.

G. B. HAZLEHURST, M. Am. Soc. C. E.—I have for sometime past held identical views with Mr. Whittemore on this subject, which he has so fully and forcibly brought to the attention of our engineers.

Any engineer who has had any thing to do with "Strength of Materials" can not but see the correctness of the statements brought forward by Mr. Whittemore, and why they should have been ignored so long by sensible men, it is hard to see.

I am decidedly in favor of a flat top rail of such proportions that the bearing area will only produce stress within the elastic resistance of the material used.

I have advocated this theory on our road for two years past, whenever the question of a new rail section has been discussed; and I go so far as to believe that the day is not far distant, when, to secure a rail of sufficient bearing area, some such section as shown by the sketch below will come into use for the two-fold purpose of increased bearing between wheel and rail, and between tie and rail.
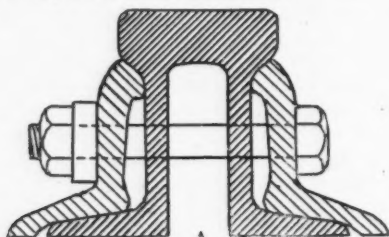
Additional splice of convenient form to be used.

Mr. J. T. RICHARDS, C. E.—It is hardly within the province of a civil engineer to remark very much on the shape of wheels.

As for the rail, it is my opinion that the top should be nearly flat. I very much doubt, however, if an absolutely flat top rail can be rolled satisfactorily.

I am firmly convinced that there should not be more than a slight convexity—say a radius of 12 inches.

Mr. W. S. G. BAKER (Prest. Balto. Car Wheel Co.)—When we began the manufacture of cast chilled car wheels, from an engineering standpoint we believed a cylindrical wheel the best form adapted for steam railway service, and so made all such wheels. As there seemed to be a prejudice on the part of railway officials to such treads, and while they favored those with cone shape, of necessity we were compelled to meet the prevailing idea.

Having no practical way to form an opinion as to relative value of the two forms of tread in their relation to rail heads, we cannot give an opinion based upon experience, but should, however, as engineers, pronounce in favor of the cylindrical tread and flat head to rail, as most likely to give increased life to both.

The first five lines of Mr. Whittemore's paper are interesting, and, no doubt, true as far as the engineers are concerned, but while they are exercising their genius to secure safety and make economy of train service possible, may it not be that their efforts are counteracted by the purchasing agent, who, from his point of view, believes he also is

accomplishing the same economy; who, from a commercial standpoint, buys cheaply—in fact he purchases his wheels per ton for about what proper metal to make such articles costs—thus causing the wheel-maker to undo what the engineer endeavors to accomplish, as his genius is taxed to produce a commercial wheel and not an engineering one—a wheel that can be made without pecuniary loss to himself, which will be accepted.

Within the last few years some of the railroads have formulated specifications based upon a physical test, and have increased the weight of chilled wheels to meet increased weight of cars and carrying capacity —in some cases as much as 100 pounds.

It would seem that this increased weight would insure increased strength, but in many cases it does not. Having recently tested wheels from eighteen different makers, we were amazed to find of what poor material wheels which will stand the specified requirements can be made, showing conclusively that the tests are not what they should be to secure proper work. Our test also demonstrated that the additional weight allowed in structure has not increased its value for strength, notably so with one maker's work, whose recently-made wheels, weighing from 555 to 575 pounds, stood an average of $1\frac{1}{2}$ blows to crack, and $4\frac{3}{4}$ blows to break under drop, while old wheels, by same maker, weighing less than 500 pounds, made some eight or ten years ago, and after many years service under cars, stood under same drop an average of $7\frac{1}{2}$ blows to crack and 25 blows to break. From our experience it is reasonable to claim that had the same stock been in the heavier structures as was in the lighter ones, with additional weight properly distributed, the heavier wheels would have stood from 40 to 50 blows to break them, and could have been made with deeper and better chill, prolonging their life, and probably giving less wear upon rail heads, as they would retain their contour and better preserve their relations with the rail heads.

If the good offices of the civil engineers could be utilized in bringing wheel-making to a higher standard of excellence, I have no doubt railroad shareholders would be benefited, and the road secure a safer and cheaper service.

THOMAS DOANE, M. Am. Soc. C. E.—A car wheel must necessarily have some lateral motion. It is given to it, to a greater or less extent, by more or less loose gauge, by all engineers, in construction. If not given in the beginning, it will acquire it very soon, by wear of rails and flanges.

The central portion of the wheel tread, whether cylindrical or conical, will get the most wear, and the tread will be worn hollow. I do not see how this can be avoided, even if running only upon flat top rails.

The consequence will be, with a hollow tread wheel, to carry the

weight of the load upon the inner and outer edges of an absolutely flat top rail, or which is far worse, the whole weight first upon the inner and then upon the outer edge of the rail. The heads of rails must be very strong to stand up under such treatment.

Such a consequence will also rock the rail upon its tie, and loosen it there, and also have an injurious effect upon the stem of the rail, bending it back and forth, as wheels carry their loads alternately on the inside and outside of the rails.

My own preference is for a rail top of such contour as to fit the average hollow tread wheel. Possibly this cannot be ascertained except by wearing wheels upon flat top rails. I think, however, it would result in a rail top very considerably removed from a flat top.

W. HOWARD WHITE, M. Am. Soc. C. E.—On reading over Mr. Whittemore's paper I notice the following, which seems to need comment:

On page 150 of Mr. Whittemore's discussion of the rail head question he says: "Giving these sections the curve in the head that they originally possessed, and with the web projecting into it, can we devise a better form for splitting the rail from the weight imposed by the wheel than is here presented ?"

It would seem as if Mr. Whittemore had forgotten a practical illustration of this particular action, with which he must have been familiar a good many years ago.

If in those days he had been told to make a stake for driving into hard ground, I hardly think he would have made the stake flat-topped, as it is a matter of such notoriety that the stake with the tapered head is the one that stands driving best.

Although I quite agree with Mr. Whittemore as to the desirability of a wide bearing for the wheel, and believe that the flat head is about the only practical way to attain that object, the argument adduced seems to me to make in favor of the other side of the question.

With a round-headed rail the overhanging sides of the head are less exposed to splitting off than with any other form.

We have only to imagine a rail with a concave head to see how much the splitting-off action of the wheel would be intensified by any flattening of the head.

Lest this should be considered a fanciful presentation of the case, it is necessary to call to mind the fact that every wheel tends to wear more or less double flanged.

Now, even if the rails were originally wide and flat, there must arise from side wear more or less narrowing of the head, to which the wheel wear will conform itself.

When a wheel so worn runs over a new unworn flat headed rail, the bearing would be on the outer edges of the rail head and the effect would be the same as with the supposed concave head.

Mr. Whittemore is evidently quite sure that there can be no such thing as fibrous interlocking of two iron surfaces, but I cannot share his skepticism until experiments on friction accompanied by microscopic examinations of the surfaces have shown that there is not a cellular formation in iron, the walls of which, when worn, may form microscopic ridges and points, bent one way or the other by the rubbing of another surface.

I have already suggested such an action as this as a possible solution of what has been ascertained by observation on German railroads, namely, the greater wear per ton of traffic in rails run over both ways as compared with those upon which the business is all one way.

It is to be hoped that experiments will be made upon this point in some of the physical laboratories of the country, and also that some great road with both single and double track lines will institute observations to confirm or disprove the German results.

Mr. WHITTEMORE.—Mr. White quite mistakes my reference to that singular sentence in the Preliminary Report of the Committee on the relation of wheels and rails to each other ; to wit: "Molecular interlocking of the fibers." The committee evidently refer to cast-iron or steel surfaces in contact and not iron surfaces as Mr. White asserts. Molecular, I need not say, is a chemical term, and any expression that implies molecular change certainly implies a chemical one also. Cast-iron and steel are generally considered crystalline in structure; hence I conclude that both the terms molecular and fibrous were misused in the sentence referred to.

WILSON CROSBY, M. Am. Soc. C. E.—With reference to the form of the rail head, I approve of the proposed flat top with small radius at the corners.

Instead of having the head so broad, as proposed, I should prefer a somewhat narrower one both for the purpose of diminishing the train resistance in cases when there was any tendency of the wheel to run either to or from flange, and also to thereby save metal to be added to the depth of the head, and thus, by its greater depth and the lessened length of the cantilevers, strengthen the top against the tendency of the sides to break off as indicated in the paper, also to oppose a greater amount of metal to be worn down.

In the wheel, I approve of the general form of tread shown in Fig. 2, Plate XLIX of the paper under discussion, but would limit the length of the flat portion to somewhat less than the width of the rail head in order that as the tread of the wheel wore it might not develop a groove near the flange.

F. M. WILDER, M. Am. Soc. C. E.—As a whole, this subject is one which should be very fully considered by those responsible for the engineering and mechanical departments of our railroads.

I believe that the tendency in railroad construction is toward too heavy weights upon the track at a single point. While Superintendent of the Motive Power of the New York, Lake Erie & Western Railroad, our limit was 13 000 pounds upon any one wheel, and in order to get greater adhesion and consequently greater tractive power, we built "Mogul" passenger locomotives, in order to get a better distribution of the weight of the locomotives and still have it on the driving wheels.

Mr. Whittemore very clearly states his proposition that we should use cylindrical wheels and flat topped rails and I fully agree with him.

In reference to the coning of the wheel having any considerable effect in assisting the truck to curve, I would say, that I do not believe it has, but that when wheels are held rigidly upon an axle and their axis is held parallel with another pair, as in a truck to a car or locomotive, the truck will roll forward on a tangent even though one wheel is much larger than the other, unless forced to an angle by some obstruction like the flange pressing against the rail, and if the axles are radial to each other, the wheel will endeavor to follow a curve proportioned to the angle of the radii.

I have experimented with a small truck on a plane and demonstrated this fact, even showing that the small wheel will take the outside of the curve if they are set wider apart than the larger ones. This fully shows that the coning of the wheel does not cut any figure in cars curving easily, but that having the trucks built so that the axles are exactly parallel is a matter of the greatest importance.

The coned wheel on a round topped rail only has a point for a bearing, consequently the only way to increase the bearing surface is to lengthen that point to a line.

The experiments mentioned on page 142 gives $1\frac{7}{100}$ square inches as the area of the points of contact as shown between coned wheels and round top of rail for 72-inch wheel, and $\frac{86}{100}$ths as the area of contact for 62-inch wheel.

The distribution of weight on this surface of contact is unequal, being greater in the center. Had the experiments or measurements been made with new wheels and rail instead of these which were "much worn," the area of contact would have been an oval with major axis much longer and the minor axis not more than three-eighths of an inch instead of nearly an inch, thus raising the rate of pressure and showing greater distress to the rail at the center of the point of contact. The effect of cylindrical wheels and flat topped rails, would be to widen the theoretical point of contact to a line and the point of actual contact would be shortened lengthwise with the rail, and would probably show a greater area of bearing than by the experiments mentioned.

Mr. C. P. SANDBERG.—Allow me first to refer to my own paper, just published by the Institution of Civil Engineers here, on "The Use of

Heavier Rails,"* in which it is said that my Goliath rail, adopted on the Belgian State Railways, is laid perpendicularly, and I may add that this was done at the recommendation of the engineer-in-chief of the rolling stock, Mr. Belpaire, who actually favors cylindrical wheels, but with the large rolling stock of the Belgian State Railways, conversion would take some time. I am not aware that the conversion has even been begun, and nowhere else do I know of cylindrical wheels, or flat top rails being used in Europe, but they get flat enough in time, and I shall have no difficulty in proving why rails are not made flat from the commencement.

First, from the producer's point of view. Any one who is acquainted with the manufacture of rails will agree that the flat top rail necessitates less pressure or work in the last groove than a round top rail, and the more round it is, the more pressure or work or closer grain in the head will be the result. The joint of top and bottom rol's, being in the middle of the head with a small opening, if the pressure or work is excessive, would leave a seam along the head in the joint between the top and bottom roll; besides, the more round the head of the section is, the better delivery would the rail have from the rolls, or the less number of wasters. Thus, it follows, that the flat topped rail would have a more porous head than the round one, and more wasters, and as a very short time in the track will make it flat enough, it would be an absolute loss, both to the consumer and the producer, to start with the flat top. See drawing attached, Plate LXIV.

Again, from the consumer's point of view. The flat top rail can never be laid in a track absolutely correctly so as to have the tire of the wheel bear on all parts of the flat surface, but it will bear on the left-hand corner on one rail, and on the right-hand corner on the next; and after a few trains have passed the line will look like a snake; therefore, the evil from the round topped rail of small bearing surface would be still worse in practice on the flat topped rail before it is worn down sufficiently to bear on the neighboring rails alike. Thus, in practice, Mr. Whittemore's suggested remedy would bring matters from bad to worse both for makers and engineers.

Now, as regards the radius. I have kept to a simple radius of 6 inches for the above reasons, but I am perfectly willing to increase it to 10 or 12, since steel rolls so much better than iron, and the delivery would be good enough with even 12 inches. After all it is of very little importance whether it is 6, 10 or 12 inch radius, as long as the top is not flat, and Mr. Whittemore's prediction that my sections would be a thing of the past is entirely premature; but I believe his flat topped rail will never become a standard section, nothwithstanding the elaborate theories of German professors, and his own poetry; besides, the thing is not new.

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* Proceedings Institution of Civil Engineers, Vol. XCV.

Plate LXIV shows a section which I had to inspect in 1869, at the Dowlais Works, for the New Orleans, Mobile & Chattanooga Railway, 16 000 tons rolled thus in iron twenty years ago, and I well remember the heavy rejection we had on account of the flatness of the rail top, and I am very glad to say that I never had one like it afterwards. I am sure no one could have wished more than I that the complaints generally heard now that the rails are not as good as those made twenty years ago, could have been remedied by such a trifling alteration in the section as making the top flat, but I think the above facts show the reason that that will not do it, but simply make matters worse. The increased pressure of the heavier engines necessitates harder steel both physically and chemically, and in this direction a remedy must be looked for. Now, as the physical hardness or what is produced by cold rolling (same as cold hammering) is not obtainable in the fast going mills used at the present day, chemical hardness or excess of carbon must be looked to as the simplest remedy, and as such hardness involves greater liability to fracture, it shows an absolute necessity of increasing the weight and the section at the same time as the hardness, if accident from broken rails should be avoided. This has been the motive of designing my Goliath rail, and my work in this direction. I am very glad to see that it is fast being adopted on both sides of the Atlantic. The reproduction of my 100-pound section in Mr. Whittemore's paper is somewhat disfigured, and to correct this in the Transaction I inclose a correct drawing of it.*

Fortunately the price of steel is being gradually reduced, which will facilitate such change with the object of securing perfect safety with more economy, and a possibility of the maker making what is wanted.

Mr. Whittemore's paper having been so ably dealt with in the *Engineering News* by Mr. A. M. Wellington, M. Am. Soc. C. E., I have nothing more to add except that I believe that it would lead to great advantage if makers had a voice in the discussion of the rail question, and I find a total absence of such, not only in this but in the general treating of the rail subject in the United States. For, after all, the possibility of making a rail is the first, and the use of it the second question; and I believe much ink might be saved if practical makers would come forward and give their opinion frankly upon the engineer's scheme.

Mr. WHITTEMORE.—When the author dictated his paper he expected his position would be opposed by many who had much to answer for in giving us the forms of rails in general use in this and other countries, and therefore he is not at all surprised at the position taken by Mr. Sandberg.

In no other device, except in the use of rails, wheels (and of the

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* Plate LXV is a reproduction of this drawing. The top line, however, is much too flat for the indicated radius of 6 inches. [ED.]

Top Roll

Bottom Roll

N. O. M. and Chattanooga Rail.
62 lbs. per yard, rolled at Dowlais,
1869.

50 tons Engine

50 miles pr. hour.

Proportion of rail section
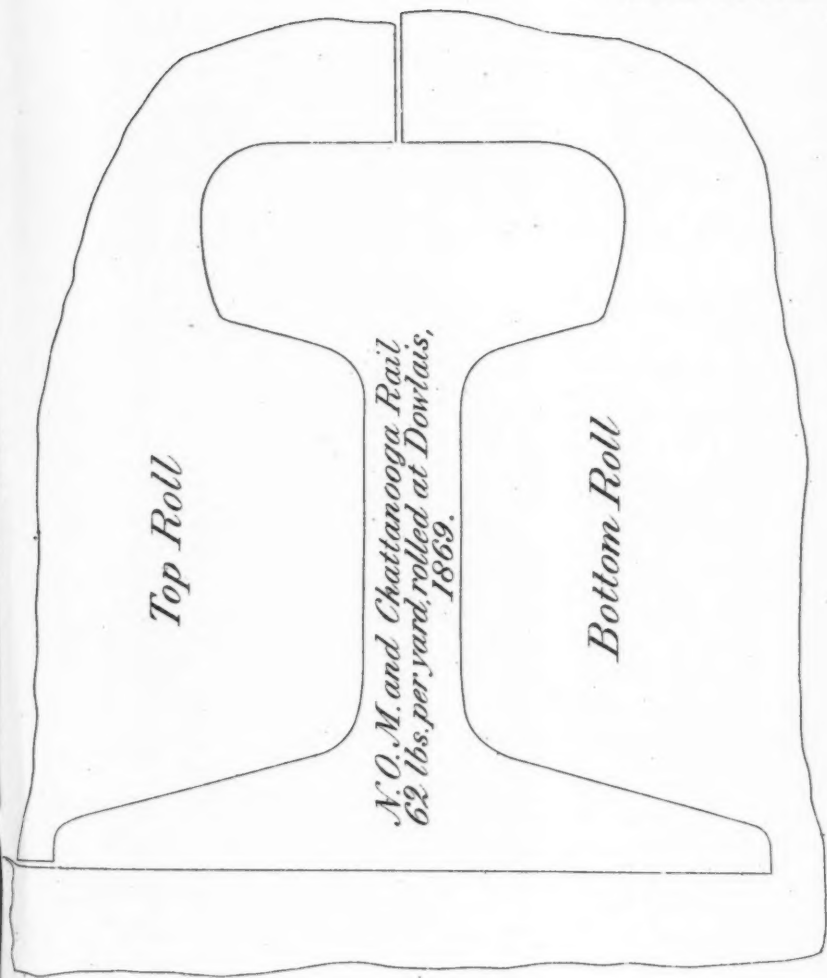
Head	-	43	per cent.
Web	-	22	"
Flange	-	35	"

100 per cent.

Equal in cost and capacity to the 80 lbs. English rail section including chairs of cast-iron.

Cheapest and best for maintenance, safety and comfort where traffic is heavy and steel cheap.
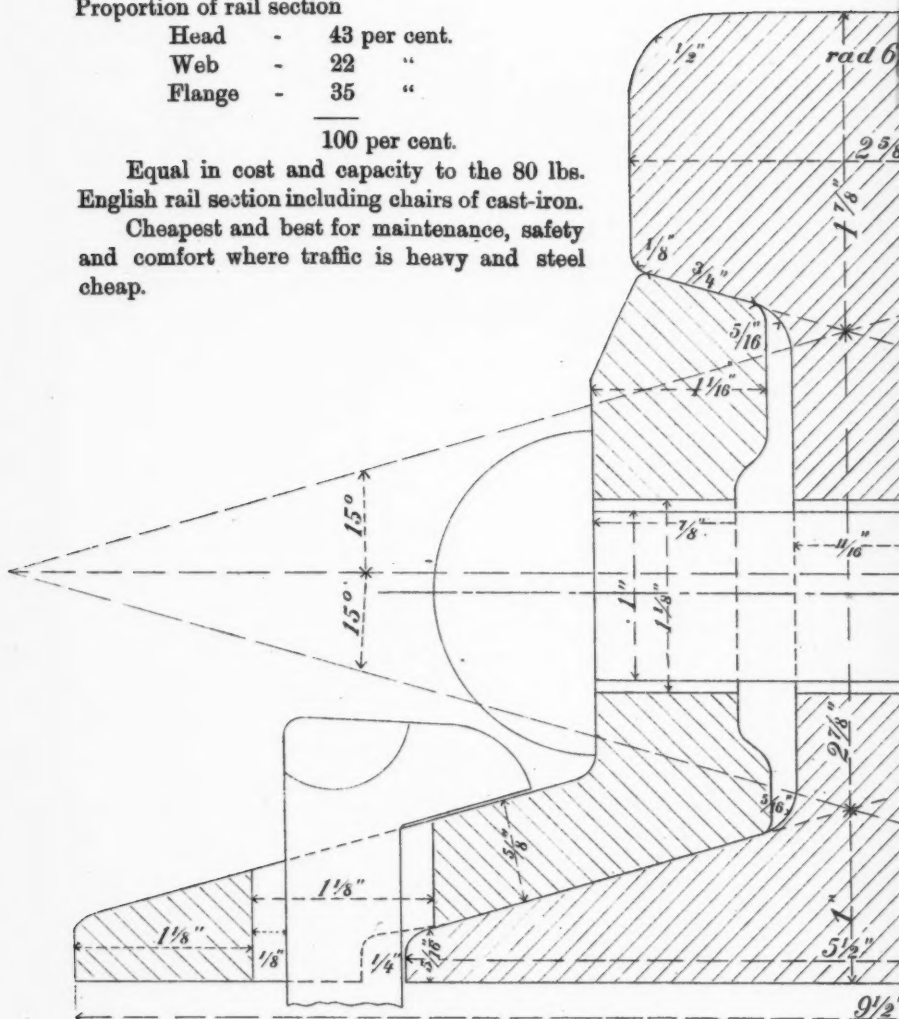
Extracted from the proceedings of t

rad 6"

2 5/8"

1 7/8"

3/4"

1/8"

5/16"

11/16"

2 1/8"

5/16"

5 1/2"

1/8"

9 1/2"

TRANS.
VO
S
WHE

100 lbs. st
50 ki

C. I
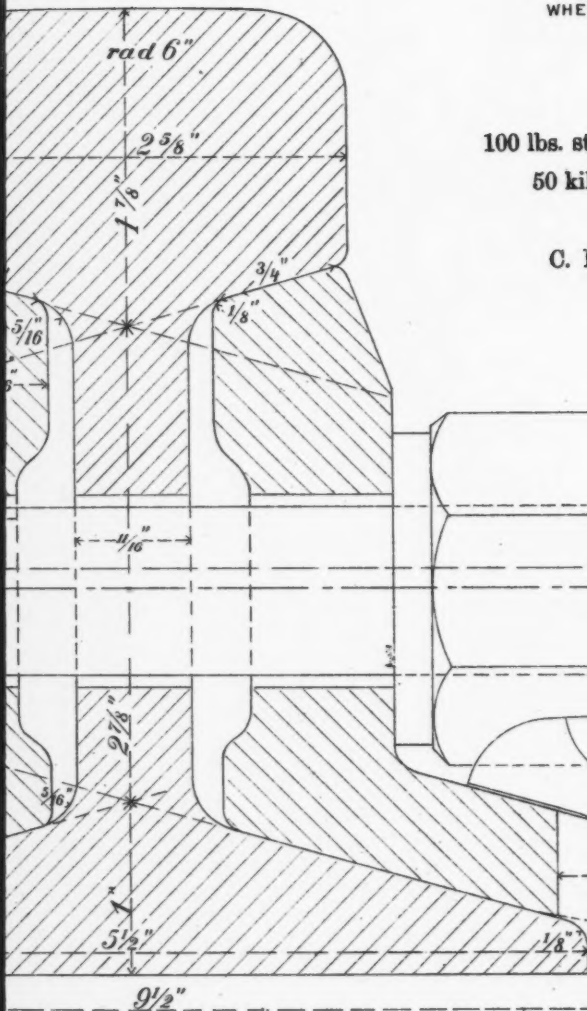
lbs. standard rail section

50 kilogs par metre.

by

C. P. Sandberg.

Centre du rail.

Centre du boulon

1⅛"

⅛"

1½"
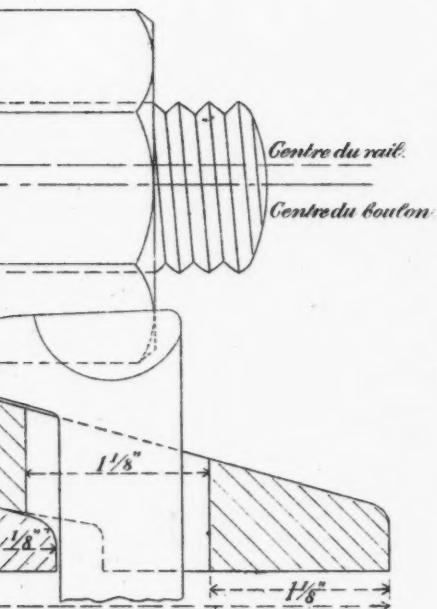
grindstone, and in the emery wheel and like appliances), does the civil or mechanical engineer subject material to much beyond one-half of its elastic limit, and I respectfully ask, where, in his discussion, he in any way attempts to state how this can be done, provided we must impose the loads we do on wheels, except by providing a broad contact between cylindrical wheels and flat topped rails. As to the difficulty of rolling such rails, that is a matter that must be accomplished by the rolling mill managers. As I have said before, a way can always be found to do that which must be done.

The difficulty he has experienced in having rails lie properly on ties is an easy matter to overcome, and at very slight expense.

In building the first railway with which the author was connected, all the ties were machine-dressed at the spot where the ties came in contact with the rail. It would be economy to do this now, whether the rails be flat or curved on the top.

Mr. Sandberg refers to a flat topped rail, the manufacture of which he inspected some twenty years ago, and he is happy to say that he has had none of the pattern to inspect since.

The author is not surprised to learn that a flat topped rail of the Brunel pattern was laid on the Great Southern and Western Railway of Ireland, so long ago as 1843-44. Some of this is still in sidings on that line and capable of standing considerable tonnage service.

The author is pleasingly surprised and gratified to learn through his friend, M. Le Rond, Engineer of the Northern Department of France, that a rail is now adopted embracing precisely the claim of the author; not, however, in degree as regards width of head, as that is not necessary since their carriage wheel-loads never exceed 6 000 pounds.

A sketch of this rail in cross-section and the specifications under which it is manufactured are so pertinent to the subject that a copy of the former, Plate LXX, and a translation of the latter are printed as an addenda to this discussion.

We must bear in mind that from forty to sixty overloaded car wheels pass over the rails to one locomotive driver, hence, the great injury resulting to rails can be attributed to car wheels.

The slighting notice given to Professor Grashof's deductions by Mr. Sandberg, I shall not attempt to answer, other than to state that I conceive his formula is proved safe by experience when the limit of elasticity, as usually determined, is entered in his formula at one-half its value. With a less margin of safety I have knowledge of repeated failures to bridge rollers and wheels under draw bridges. Mr. Sandberg says that it is immaterial whether the rail has a curved top of 6, 8 or 12 inch radius—that it will get flat enough in time, etc. Of course, the rails do get flattened through the struggle they have with the wheel, and in this warfare the wheel is being made hollow in the tread, both of which disastrous operations it is the object of my paper to correct.

In designing all our structures (except perhaps rails) the engineer is expected to be guided by reason as to size and forms of their different parts; but in this instance Mr. Sandberg asserts that it is immaterial whether a radius of 6 or 12 inches is used in forming a surface over which the bulk of the land tonnage service of the civilized world passes. Is this true engineering?

In regard to the statement that my representation of the Sandberg pattern of rail is not correct, I have only to say that it was intended to reproduce it from the sketch and dimensions given by Mr. Sandberg in his paper as published in Vol. 84, page 395, Transactions of the Institute of Civil Engineers.

With Mr. Sandberg, "I believe much ink might be saved if practical makers would come forward and give their opinion frankly upon the engineer's scheme." It seems to me that I have burned a deal of powder to blow over a feather; that when real thought, logical reasoning and common sense, all lead directly in one direction, there can be no question of what is necessary, and if we have not the appliances or methods for meeting the conditions the problem engenders, it is the duty of the engineer, whether he be a theorist or a manufacturer, to meet and solve the problem at once.

I am not one to willingly admit that the engineer, in his profession, should be considered the impracticable factor behind or before the manufacturer. The one should and will supplement the other, and what true engineering demands will be met by the manufacturer in so far as human ingenuity will permit.

E. T. D. MYERS, M. Am. Soc. C. E.—I have read with much interest Mr. Whittemore's paper on wheels and rail heads. Although I have been forty years engaged in engineering, most of the time upon railroads, and have seen the fashions of rail sections vary almost as much as those of apparel, I am not competent to say much upon the subject. First rate material will, I think, give satisfactory results in almost any of the forms which have prevailed. Yet I will go so far as to say that I prefer a top broad and nearly flat, if not absolutely so, and I do not adhere to the inclined sides of the rail head.

G. BOUSCAREN, M. Am. Soc. C. E.—Using without abusing is a dictate of common sense, it is the exercise or application of a power within certain defined limits, beyond which it loses the faculty of being repeated or re-used in the same manner; going beyond these limits being tantamount to destruction or waste.

Hence, if economy of power is the first object of the engineer, no greater professional sin can be committed by him than to tax materials beyond their limit of elasticity.

We often err by force of habit, dating from early days, when perhaps the same position was perfectly legitimate; by the process of evolution,

use may become abuse; such seems to be the case with regard to the present relations of rails to wheel-loads.

As long as the loads were kept within the limits of 2½ tons for car wheels and 5 tons for engine driving wheels, the rail heads appeared to be well enough adapted to the purpose for which they were intended; although the fact, that the round shape of the head was productive of increased wear of rails and wheels, was even then recognized, is shown by the gradual changes observable both in Europe and America toward a flatter top; but now that we have been led, through the necessity of reducing the cost of transportation, to increase these loads to 5 tons for car wheels and 10 tons for engine driving wheels, with a tendency to a still greater increase, it is evident, from the facts presented by our honorable Past President:

First.—That we are abusing the rail head and wheel-tread by subjecting the metals thereof to repeated pressures beyond their limits of elasticity.

Second.—That in so doing we are decreasing the length of rail and wheel services, which are both important factors in the cost of transportation; that an increase in wear means an increase in frictional resistances, which is also an important factor in the cost of transportation.

Third.—That as a necessary corollary of the above, we are losing through the increased wear and tear of rails and wheels and loss of power, a considerable part of the advantages sought to be gained by the increase in the carrying capacity of our cars and in the hauling capacity of our engines.

If these premises are correct, we cannot apply the remedy too promptly, and if the metals of the rails and wheels are to remain the same, the only remedy is obviously an increase in the bearing surface between the two.

I would not say absolutely with Mr. Whittemore "cylindrical wheels on flat topped rails," because, if by "flat topped" is meant (as illustrated in Fig. 2, Plate XLIX, showing the suggested arrangement) a plane surface, it will not give in normal running conditions the greatest bearing surface; this maximum surface of contact can only be secured by giving to the rail top the shape that it will take ultimately after a prolonged service; this shape must necessarily vary on different roads, according to the depth of grooves allowable on the engine driving wheels and car wheels, but will always be a slightly curved surface, until the general use of equalizing brake shoes, which prevents the formation of the grooves and maintains the cylindrical shape of the wheel-tread, shall gradually cause the flattening of the rail top into a plane surface in normal running conditions.

Mr. Whittemore has specifically limited his inquiry to the influence of the shape of the head; although I cheerfully recognize the impor-

tance of the shape and size in that most indispensable of all organs, it is, I think, also generally acknowledged that the quality of the substance inclosed therein should not be overlooked, and it may perhaps be best in a study of the survival of the fittest, not to start out by separating the head from the body.

If the question before us is how to design and construct a steel rail better adapted to the altered conditions of American railway traffic than the short lived rails now so extensively used in the United States, I think the shape of the rail, its weight and the quality of the metal are three factors of about equal importance, and so closely related and co-dependent on each other as to be inseparable in any consideration of the subject aiming to practical results.

If it is true that the bearing surfaces between rail and wheel are entirely inadequate to the present wheel loads, it is, I think, equally true that the steel of the rail is generally too soft and open-grained through an insufficiency of carbon and mechanical work. In the early days of steel rails they were made much harder in imitation of what was being done in Europe and they gave much better service. A very large proportion of the 52-pound rail, laid on the Cincinnati Southern Railway, when it was constructed in 1876, is still in the track and shows less sign of "flowing" and crushing in the head than some of the 60-pound steel by which it has been partly replaced, although the head of the 60-pound rail is fully $\frac{1}{8}$ of an inch wider; manifestly this result can only be ascribed to the superior hardness of the 52-pound rail.

It may appear singular that as the wheel-load has increased, the metal of the rail should have been made softer instead of harder; this is explained by the widespread confidence placed in Dr. Dudley's theory as to the superior wearing quality of soft rails, for several years after the publication of his paper, and also by the fact that the early hard rails were found to be too brittle, many of them breaking in the track and causing innumerable accidents; this was the case with the 52-pound steel laid on the Cincinnati Southern Railway; hence the remedy sought in the use of a softer metal containing from 0.30 to 0.35 of carbon instead of 0.40 to 0.45.

To make matters worse, contemporaneous to this change, happened several "improvements" in the manufacture of rails, whereby a less number of passages through the rolls and a high temperature of rolling so reduced the cost of production as to place it within the reach of the most fastidious railway manager whose practical economy prefers pot metal at $30 to good steel at $33.

Although a strong partisan of the larger bearing surface, advocated by Mr. Whittemore, I earnestly believe that the flowing and disintegrating of metal, and the coring and splitting of heads observed by him and many others, myself included, is principally attributable to the bad quality of the steel. I think that the remedy is to be found, not only

in cylindrical wheels on flat topped rails, but in a return also to a harder steel, sufficiently rolled at the proper temperature.

To avoid brittleness, as well as for a due regard to economy in maintenance, the rails should be made much heavier.

My experience is, that, with very few exceptions, the breaking of steel rails in the track begins at the flanges, this is an indication that the flanges should be made narrower and thicker.

In the paper of Mr. Caillé (*Notes sur l'acier à rails et sur la durée des rails d'acier—Comptesrendus de la Société des Ingénieurs Civils, Année,* 1886, 2me Vol.) on the bearing qualities of two different makes of r on the Paris and Orleans Railway, the analyses given of these rails, show the proportion of carbon to have been 0.6 to 0.7; the wear had been 8 millimeters in twenty-one years' service, and the author estimated that they were good for ten years more; these rails weighed 76 pounds per yard and did not break in the track, but they were double-headed rails.

I do not think that it would be advisable to use steel of this grade in a flange rail of the same weight, but I believe it is entirely practicable to make a heavier flange rail quite as durable and safe.

In a late paper read before the Institution of Civil Engineers, Mr. Sandberg points out the necessity for narrower and thicker flanges, and proposes the use of tie-plates to increase the bearing area of the flanges on the tie; I think well of this suggestion and believe that the increased life of the rails and ties would well repay for the cost of the tie-plates.

In conclusion, I would sum up as follows, the requirements considered to be necessary for a safe and durable rail, under the present conditions of wheel-loads and speed on American trunk lines:

First.—Weight—Not less than 80 pounds per yard; 100 pounds preferred.

Second.—Shape—Head—Flat topped (shape taken by the top surface of the head after a prolonged service) with vertical sides and sharp rounded corners.

Flanges—Not less than $\frac{3}{4}$ inches thick on edges.   Quantity of metal in flanges equal to that in head, less a wear of $\frac{3}{8}$ or $\frac{1}{2}$ inch.   Slant of flanges and head equal.

Third.—Metal—Close-grained, uniform and tough; well rolled, and finished at a dark red heat.   Tensile strength not less than 105 000 pounds, not more than 125 000 pounds.   Probable carbon 0.45 to 0.55.

Such rail should stand a traffic of not less than 20 000 000 tons for a wear of $\frac{1}{16}$ inch, and should give a life service of from 120 to 160 millions of tons.

The rail mills have always claimed the privilege of determining for the railway companies the quality of steel most suitable for their rails; I think this should be entirely satisfactory, provided the mills would also be willing to guarantee a rate of wear under service, below a reasonable maximum, say $\frac{1}{16}$ inch for 20 000 000 tons; but as long as they decline

this responsibility, it is nothing more than fair and just that they should work under specifications prepared by engineers.

Mr. GEORGE GIBBS, Mech. Engineer.—Mr. Whittemore's very sugges-tive paper cannot fail to call attention—and none too soon, I believe—to the effect of the steadily increasing wheel-loads of modern cars and loco-motives upon the wear of rails; by "wear," meaning the sum total of defects developed in service and not abrasion alone. The portion of the problem connected with car design is now receiving very careful attention from master car builders throughout the country, and the necessary strengthening process from the roof down to the wheel-tread is going on· But right here we are met by inflexible conditions, the contact surface offered us to-day by the modern rail head is substantially what it was fifteen years ago; the radius of the upper corner and slope to sides have increased or diminished according to varying dictates of fashion, now appearing to be on the return cycle towards small radii and vertical sides, but the available width of rail tops has undergone slight change·

It seems to be high time that rail and rolling stock designers con-sidered this subject from a common point of view. Mr. Whittemore's figures show very clearly that the effect of increased load upon tires is not to be ignored, and there is no reason to suppose that rails enjoy im-munity from punishment from the same cause. Some car designers are seriously considering the advisability of using a six-wheel truck for the high capacity freight cars coming in use, very largely on account of the impaired life of the wheels under the increased pressures entailed. I believe it is a demonstrable proposition that the life of our wheels is being appreciably shortened from this cause. Does not Mr. Whittemore's suggestion, then, offer a more direct solution of the problem?

I say, it can be proven that increased pressures cause increased wear, and I also believe we have proven that increased contact surface dimin-ishes wear. In the discussion of your Committee's report on rail forms will be found a form of wheel designed by Mr. J. N. Barr, M. Am. Soc. C. E., and now largely in use on this road (Chicago, Milwaukee and St. Paul), in which the available contact surface of rail head is more fully utilized than in the usual form of conical tread. In this tread, it will be noticed that besides altering radii at throat, the main bearing portion is formed to a curve having the same radius as rail head—10 inches. In Mr. Barr's absence, I have not at hand figures for relative performance of these wheels with those having tread of usual design, but can state generally that results have been most satisfactory, which is confirmatory evidence in the direction we desired.

Now, in regard to Mr. Whittemore's proposition definitely; looking at it from the direction of its effect upon rolling stock, I heartily second the attempt to provide increased contact surface between wheels and rails by increased width and parallelism of surfaces, but am doubtful of

the effect of the particular method of securing it by flat tops and cylin-
drical treads having their contact in a horizontal plane, upon flange
wear of our wheels. Car trucks are seldom found with perfect parallel-
ism of frame and axles, so that the tendency in all trucks is to run more
or less to one side. This is appreciably counteracted by either coning
wheels, inclining the rails, or the form given throat of wheel, tending
to equalize wear over whole tread by causing end oscillation of axle.
Do we not remove a large factor in this desirable action by surfaces so
disposed as to be in equilibrium in any position assumed? I am here
supposing the extreme case of cylindrical wheels with the usual sharp
fillet, $\frac{1}{4}$ to $\frac{5}{8}$-inch radius, at the throat. In Mr. Barr's wheel, coning
is dispensed with, but an intermediate curve of $1\frac{1}{2}$-inch radius is formed
between throat and tread, which I believe supplies the needed condi-
tion for distribution of wear.

From an examination of a considerable number of plaster casts taken
of rails in track and tracings of wheel-treads in all stages of wear, I
am inclined to think that the contact area between the two very rapidly
approximates the maximum allowed by width of rail head after the
wheels are put into service, so the question of parallelism of surfaces
very quickly solves itself.

I am, therefore, of the opinion that we should consider a rail having
sharp corner curve, as wide a head as the weight of the section and safe
rolling conditions will allow, and radius of top at least as great as 10
inches; wheel-tread to be modified in throat in some such manner as Mr.
Barr suggests, the remainder of tread to be of same curve as rail top.
In this manner we will preserve uniformity of wearing conditions under
varying conditions of track surfacing, curvature, etc., in the best possi-
ble manner.

It may hardly be the place here to discuss the best section of rail
throughout, but I believe that we can with advantage considerably
modify the present proportions without adding to weight, if so desired,
by adopting Mr. Whittemore's suggestion as to width of head, increas-
ing height of rail and its strength consequently as a girder, adding
little or nothing to web thickness, but equalizing amount of metal in
head and foot by adding to foot, narrowing same to obtain good distribu-
tion of metal for rolling and favorable shrinkage conditions. Here we
would have a rail which would leave the mill in the most perfect phys-
ical condition, and in the track would offer the least contact pressures
with ample material for abrasion and would have sufficient stiffness as a
girder to lessen the difficulty of keeping track in surface. With better
surface the "hammer blow" would become a less important factor,
harder material would be allowable and the percentage of rails removed
for battered ends, less.

In the table Mr. Whittemore has given (page 148), showing results
we have obtained from some analyses and physical tests of rails, the

first ten samples on list were from rails removed from track after only
two to three years of service for excessive wear or crushing. In every
case the photograph of etched section showed the undoubted cause of
the wear; thus, in Plate L, an etching of sample 66b, will be noticed
a zone of flattened blow-holes enveloping the entire section about ¼ inch
below the surface; these appear beautifully clear in the photograph,
but not so well defined in the engraving. Sample 72b shows spongy
section throughout, apparently from a frothy ingot; the high silicon
would here appear to indicate imperfect conversion, as the physical test
of rail shows cold-short rotten, rather than hard and brittle material.
Almost the identical amount and distribution of hardeners in a different
make of rail, and one made, I believe, by a different process, shown
by 52b, produced most excellent physical results, and from the etched
section and behavior of the metal under the tool in machine shop, I
should predict excellent results in track.

Not to follow analysis of table further, it is apparent that the most
variable chemical and physical characteristics prevail in steel rails, and
that failures are many times to be explained by undoubted physical
defects, defects certainly not traceable to design largely, but rather to
some undetermined relation between chemical composition and physical
treatment in the mill, a relation not clearly revealed to us by the ordi-
nary chemical and physical tests which give reliable indication of the
quality of other structural material.

Mr. WHITTEMORE.—In regard to the form of wheel tread as designed
by our member, Mr. J. N. Barr, cited by Mr. Gibbs, I have it from Mr.
Barr that he so formed the tread of his wheels to best meet the blunder
of the curved top rail; it was in his power to control the one and not
the other in his own field of work, and it is my opinion that he has met
the fault he did not control as thoroughly as he could.   I have it from
Mr. Barr, personally, that could we have flat topped rails he would have
his wheels cylindrical.

L. L. BUCK, M. Am. Soc. C. E.—If we do not see any tests of the
efficacy of using cylindrical wheels and broad flat topped rail heads
until there is a general movement of railroad companies in that direc-
tion, it is probable that we shall have a long time to wait.   There is still
a strong prejudice in favor of the coned wheel, and so long as coning
continues in general use, a large part of the advantage of using the flat
topped rail would be lost.   Still it would prevent the destructive effect
upon the rail head caused by the cylindrical driving wheels as illus-
trated in Mr. Whittemore's paper.   Of course, a new coned wheel
would not have much bearing upon it, nor would a badly worn
wheel, and the consequence would be that they would, in a short time,
wear broader bearing surfaces for themselves, and that in time they
would round the top of the rail.   Were the wheels cylindrical and the

heads of the rails broad and flat, the same result would take place, but not nearly as rapidly as with the coned wheels. There would always be a portion of the surface of the wheel which would wear more rapidly than any other part, thus forming a more or less shallow groove, which, in turn, would round the top of the rail. The amount of such wear would depend upon the proportion of such worn wheels to the new ones in use and upon the extent to which the wheels were permitted to wear before they were "trued up" or replaced. But it would be absolutely impossible to keep the tops of the rails perfectly flat.

If now there is a chance that the life of the rail would be increased by making the greater portion of the top of the head flat, there seems to be no reason why the experiment could not be tried now as well as at some future date. If some railroad company having occasion to order a large lot of rails, should ask for enough flat topped ones to lay several miles continuously, followed or preceded by the present form of head, I do not believe they would be taking any risk. The rails could not wear out any more rapidly, and it is reasonable to suppose they would not wear out as rapidly, for the reason that after having become rounded on top they would still be as good as the ordinary rail, and we should have the time it required to wear them to that condition as a nearly net gain.

One of the objections that I have heard used against the flat surface of the head is, that in rolling such a rail pieces of cinder or scale are liable to get between the rail head and the shoulders of the grooves of the rolls and cause cycloidal scratches on the top of the rail. I do not think, however, that this would be difficult to overcome.

Should the experimental piece of track show satisfactory results, it might encourage somebody to experiment on cylindrical wheels, and ascertain whether the loss due to the resistance on curves (if such resistance is thereby increased) was not more than compensated by increased life of rails and wheels.

MOSES BURPEE, M. Am. Soc. C. E.—I consider a wheel of which the greater portion of the tread, or say about $2\frac{1}{2}$ inches, is cylindrical, a better one than the ordinary conical wheel. That the latter does not give entire satisfaction is evident from the present discussion. To discover the faults which underlie its failure to do so and to present a plan by which these faults may be eliminated is a duty which no engineer should shirk.

The benefits expected from the coning of wheels are in practice seldom realized, I believe, even in new wheels on good track, and still more seldom with worn wheels on either good or indifferent track, probably never when both wheels and track are in poor condition.

The wear which is certain to occur after a few months use is either to reduce the diameter near the flange to at least as small, if not a smaller one than that near the edge of the tread, in which case the tendency on

curves to press to the outer rail results in bringing as large, if not a larger, diameter on the inside and shorter rail, or the reverse of what is supposed to be obtained by coning the wheels.

While it is one thing to demonstrate that the practice of coning wheels is probably useless, it is, of course, another thing to show that there may be something gained by adopting the cylindrical wheel proposed by Mr. Whittemore.

I think it has been plainly shown by the diagrams made of worn wheels, with which all are familiar, that the object of the practice of coning is seldom attained and never for a long time held.

There can probably be no doubt that cylindrical wheels are much more liable to run in a straight line with less lateral pressure on either rail than conical ones are. To illustrate, suppose we have a set of new conical wheels on good track, just leaving a curve and with the flanges against the outer rail. The tendency is, as soon as it gets on tangent to run toward the other rail in order to bring the equal diameters of the pair in bearing. The momentum as well as the direction of the wheels will carry it beyond that point and reverse the order, which will also in turn reverse the motion, and a series of vibrations will be kept up for a length of time which depends much on the condition of track. I believe this motion exists on the best track in a slight degree, and on indifferent track to a greater degree, and is aggravated by every imperfection of line or level. If this is so, there must be a good deal of consequent flange friction and wear, as also a tendency to spread the gauge of the road, especially where soft wood ties are used. I believe, therefore, that there is a constant and growing tendency for conical wheels to injure the track they run upon, and that this tendency would be almost, if not entirely, eliminated by the use of cylindrical wheels, in so far as the lateral vibrations are concerned.

The objections to cylindrical wheels on account of inadaptability to curves, has, I think, not been shown to be greater than actually exists with conical wheels, that are even slightly worn, and, inasmuch, as by far the greater proportion of the mileage of the railways of the country is straight line, it must be better economy to provide for circumstances of the most frequent occurrence by what can be shown therein to work well, and fairly well at least in less favorable circumstances, than to sacrifice a good thing for the sake of one which has been supposed to work well in the less frequent, and tolerably in the more frequent, cases of ordinary practice, but which has been found wanting in either.

While I am satisfied that a cylindrical wheel as proposed by Mr. Whittemore would be an improvement, even on the ordinary rail now used, I believe its chief merit lies in the opening it gives, or would give, for the adoption of a flat top rail—thus securing much better conditions for wear, of both wheel and rail, as well as for adhesion.

I presume there would be but little difficulty in rolling such a section,

as it would be but little more than half the width of the flange, which is at least nearly, if not quite, flat, and would favor as large a radius for the crown of rail as possible, should a perfectly flat one be impracticable in manufacture.

WATERMAN STONE, Assoc. Am. Soc. C. E.—I have not quite outgrown the effects of my early education as to the coning of wheels, and I am of the opinion that rails rolled with a top radius of 11 or 12 inches are to be preferred to those with a flat top. While I deprecate the multiplication of rail patterns, I hope that some road will be found with sufficient courage to give Mr. Whittemore's plans the test of experience.

E. PONTZEN, Cor. M. Am. Soc. C. E.—In some remarks on the report of the Committee on form of rails and wheels I said: "I would admit the 12-inch radius or even a flatter top, but only if the tread of the wheels is cylindrical."

I said further "the flatter top reduces the chances of producing grooves in the tread."

On these points I am of the opinion of Mr. Whittemore as regards the top of the rail. Like him, I am afraid of the "out-squeezing" of the top of rails, what he named the outflow of the metal; and for that reason I had wished to avoid bringing the bearing of the wheel too near to the lateral face of the rail. But I agree with Mr. Whittemore in considering the increased surface of contact between wheel and rail as very useful in this respect.

The efficiency of conical wheel treads, and, as a consequence of it, of a rail top not flat, for the passage of wheels through curves, is absolute as long as we consider a single axle; but when two axles are connected, the advantages of the cones are diminished, and this the more as the distance of the axles increases.

The wear and tear of rails and wheels results from two causes: the rolling motion under too high pressures and the friction. With flat rail tops and cylindrical wheels the first will be much reduced, but at once the second will increase, as in curves cylinders of the same diameter will have to make longer runs on the outside rail than on the inside rail. The axles of the wheels will have to support the increased torsion stress, which changes direction with the direction of the curves.

When the wheel treads are grooved, the contact face between rail and wheel is increased and the advantages of conical wheel tread disappear, the first cause of wear will diminish, the second increase. But the conditions will not be then quite the same as when the wheels should be cylindrical and the rail top flat. The groove will come in aid to the flanges; but it is of no great use, and I mention it only.

Another difference is of more importance, as long as the flat top rails

are not of general use, and as long as grooved wheels will therefore run on the lines which will have introduced the flat top rail, the bearing of the grooved rails will be entirely on the edges of the rail head of the flat top. This drawback would be avoided with rails not having a flat-top. I am also afraid that the rolling of flat tops would present some difficulties.

In conclusion I would say that cylindrical wheels and rails with curved top of more than 12 inches radius, say 15 inches or more, would prepare for the future a good way and prevent for the present the danger to which flat top rails are exposed by grooved wheels.

I believe that Mr. Whittemore proposed only the Strickland or Brunel rail, in view of the bad effect of grooved wheels on the Stevens or other single flange rail. In my mind we will never return to the U rail.

A. GOTTLIEB, M. Am. Soc. C. E.—I fully agree with the author that a larger surface contact between wheels and rail would reduce the excessive crushing strains, per unit of surface, on both, and thereby enhance the life of both rolling stock and track. That this can be achieved by cylindrical wheels and flat topped rails, as long as they are new, or can retain their original shape, is equally true; but, can this be done?

It seems to me that such shape of wheel and rail top would answer best, which through continuous use and abrasion would bring more and more surface in contact, instead of having such contact from the start with new material, and diminishing the same through actual service. Rails with curved tops and sharp corners, and conical wheels with obtuse angles between rim of wheel and flange, seem to me to be approaching this condition better than those suggested by the author.

That the rails do not render service until they are worn out, but deteriorate a great deal faster, is, in my opinion, not exclusively due to the heavy pressures imposed upon them by the locomotive driving wheels, but more so to the high speed, imperfect tracks and faulty joints. In this respect the shapes suggested by the author would not remedy the evil. The style of joints mostly used at present, angle bars bearing under the head of the rail as well as on the foot of the rail, seems to me a barbarous abuse of the rail; it reminds me of a slugger of studied cruelty, who uses an ingenious device to hit the corn on the toe with the same blow he deals to the head of his victim.

The imperfections above mentioned cause the life to be pounded out of the rail, before it has time to be rendered worthless by wearing. The same is experienced with good sound oak cross-ties, that naturally ought to do service for about seven years, while on roads with heavy traffic and high speed of trains they do not last more than two or three years. The life is pounded out of them, said an experienced engineer to me some time ago.

On page 148 Mr. Whittemore states as follows, with reference to the test made by the Chicago, Burlington and Quincy Railroad with new and old rails: " It will be observed that these tests do not show any remarkable change through use;" and again, " While the appearance of the photographic etchings can be sometimes observed in new rails, owing, as is believed, to faulty manufacture or of design, yet fractures of this rail before use did not show such defects of structure.

"It is the slow but fatal development of an internal organic disease in a structure that is not organic, if we may borrow an idea from a present report, a sort of tuberculosis disease, with its slow-forming cavities."

Now, while I fully agree with Mr. Whittemore as to the latter statement, I beg to differ materially with him as to the showing of the test results above referred to in the first part.

Considering the first fifteen tests of the table, made with rails manufactured by " F," which presumably are of the same material, it will be noticed, that while in the new rail the ultimate strength is high, it is low in the specimens from old rails. Again, while the elastic limit for the new rails shows an average of 52 per cent. of the ultimate strength, it is in the old rail 60 per cent, and the elongation in new and old rails $9\frac{2}{10}$ and 18 per cent. respectively.

The larger elastic limit and elongation, combined with lower ultimate strength, in the old rail specimens, tells, I believe, the whole story, and explains also the cavities shown on the etchings. The life has been pounded out of the rail before it had time to wear out.

These test-results are perfectly in accord with the experience of testing laboratories, or of engineers having experience in testing eye bars for bridges. If a bar is tested and is strained slightly beyond its elastic limit, then removed from the testing machine and allowed to rest for a time, say a few weeks, and then again the test continued, it will be found that the so tested bar will show new life, and the elastic limit will be higher than the first time; the elongation will be greater, but the bar will ultimately fail suddenly with greatly reduced ultimate strength from what might have been expected. It reminds one of the last effort of ebbing life in a sick and dying person; the remaining spark of life has concentrated its efforts to a last resistance, but after that the collapse is sudden.

The few tests referred to are scarcely sufficient to warrant positive conclusions, but, in my opinion, point in the direction indicated. It would be very desirable to have more tests with new and old rails of the same material, to determine the facts.

If, however, my views, here expressed, are not erroneous, the remedy is not so much in the shape of rail-tops and wheels, but in the proper weight of rails, with reference to the traffic and speed of trains, the better distribution of the weight over all the wheels of the locomotive, perfect track and sound couplings at rail joints.

J. FOSTER CROWELL, M. Am. Soc. C. E.—In this able paper Mr. Whittemore has definitely described and located one great evil, and suggested a remedy; indirectly he has referred to others in the same field hardly less great; and it would seem that we cannot proceed very far in discussing the form of the top of the rail and of the wheel before we encounter positive and insistent questions of the form of the rest of the rail, of its process of manufacture, of its support and fastening in the track, and of its maintenance in the planes in which it is placed.

Probably there is nothing else in the whole range of railroad appliances for which so little is done and of which so much is expected as the modern rail. It is conceived, in the converter, in sin, and born from the rolls in iniquity; it is tortured and beaten to correct the faults of its pre-natal days, and put out of shape so that it may sit up straight; it is then taken out with its fellows, thrown violently down a steep place, put into an imperfect track, with yielding, shifting, shrinking support, subjected to the weight and impact and pushing of loads that far exceed its strength; at length it expires, still in early life, and when the learned doctors come to decide why it did not live, they take the shape of what is left of its poor head and consult phrenologically. It is not too much to say that important as the relation is of the top of the rail (and the tread of the wheel), it is no more so than the relations which concern its footing.

The merits of Mr. Whittemore's suggested arrangement seem to me evident; it would certainly appear to be the natural arrangement for rails on straight lines.

There was at one time a belief that the coning of wheels caused them, when on straight track, to take and maintain through gravity a central position between the rails. This tendency is the only advantage of coning; with partly worn wheels it diminishes or altogether disappears. On curves, especially where sufficient elevation is not secured, the advantage of the flat topped rail is not so marked, for the reason that in taking position against the outer rail the wheel will ride up on its fillet, and all the weight will come upon the rail corner. This, it is true, is a condition no worse in its extreme case than exists with the curved top rail, but the fact calls for attention, and suggests the query whether we should not have a special type of rail for outsides of curves; those rails aggregate in this country about 12 per cent. of the entire service—a very small minority to govern when their requirements are so much greater.

It is probable that if flat topped rails are introduced it will be before all coned wheels have disappeared, and it would in that case be necessary to adapt the outer curve rail for coned wheels, by giving inclination to the top.

In regard to the relative wear of flat topped and curved top rails the deductions of Mr. Whittemore seem to me convincing.

$1\frac{9}{16}''$

$\frac{15}{32}''$

$1\frac{1}{16}''$

$\frac{5}{8}''$
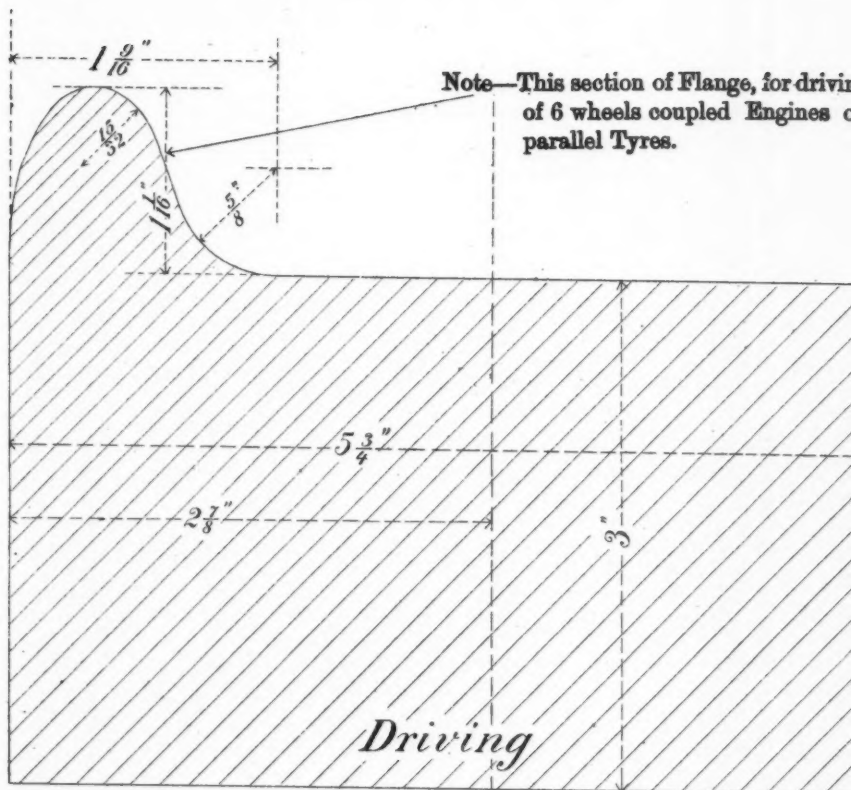
Note—This section of Flange, for drivin
of 6 wheels coupled Engines o
parallel Tyres.

$5\frac{3}{4}''$

$2\frac{7}{8}''$

$3''$

Driving

$1\frac{1}{8}''$

$\frac{3}{4}''$

$\frac{5}{16}''$

$\frac{1}{8}''$

$\frac{1}{4}''$

$\frac{3}{4}''$

Lip for C

GOODS ENGINES.

driving-wheels
ines only, with

$1\frac{7}{8}''$

$\frac{9}{16}''$

$1\frac{1}{8}''$

$\frac{5}{8}''$

Taper, 1 in 20.

$\frac{5}{8}''$

$\frac{3}{8}''$

$\frac{3}{8}''$

$5\frac{3}{4}''$

$2\frac{7}{8}''$

$3''$

Engine

Leading & Trailing

$1\frac{5}{8}''$

$\frac{5}{8}''$

$\frac{1}{2}''$

$\frac{7}{16}''$

$\frac{7}{8}''$

for Cast iron Wheel.

$\frac{5}{8}''$

$\frac{1}{2}''$

$\frac{7}{16}''$

$\frac{7}{8}''$

$1\frac{5}{8}''$

$\frac{3}{4}''$

$\frac{5}{16}''$

$\frac{1}{4}''$

$\frac{1}{4}''$

$\frac{1}{2}''$

Lip for Cast iron Wheel.

$1\frac{27}{32}''$

$1\frac{7}{8}''$

$\frac{5}{8}''$

Tape

$2\frac{7}{8}''$

$5\frac{1}{2}''$

Engine

$1\frac{1}{8}''$

$\frac{3}{8}''$
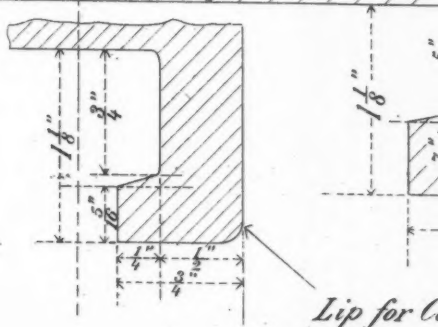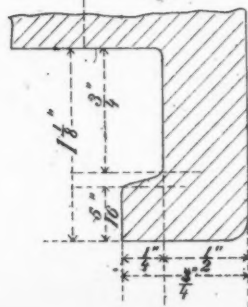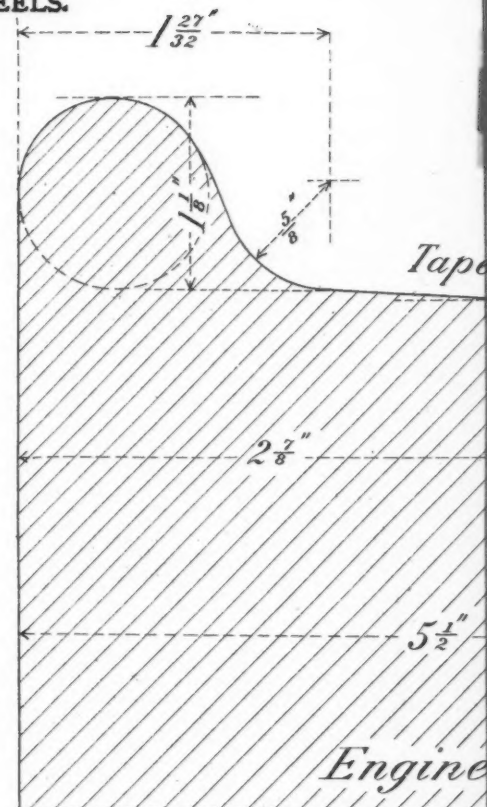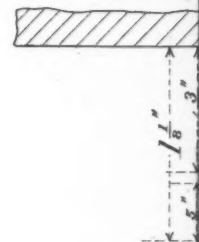
SECTIONS OF TYRES.
FOR ENGINE, CARRIAGE & WAGON WHEELS.
FINISHED SIZE: CREWE WORKS.

PASSENGER ENGINES.
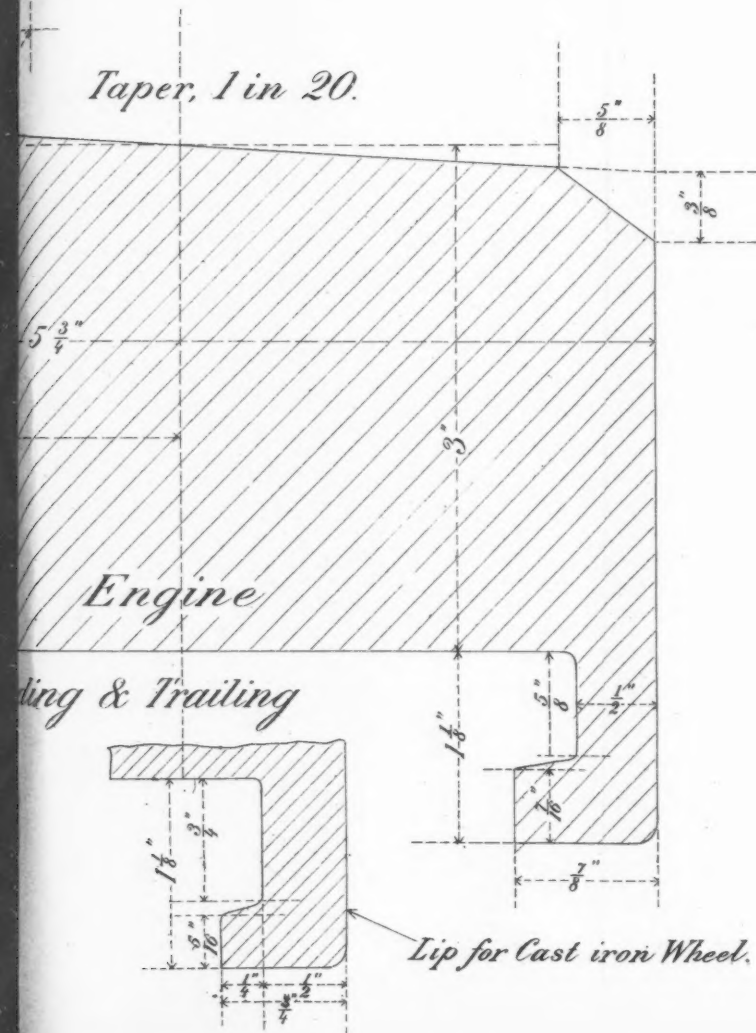
Taper, 1 in 20.

Taper, 1 in 20.
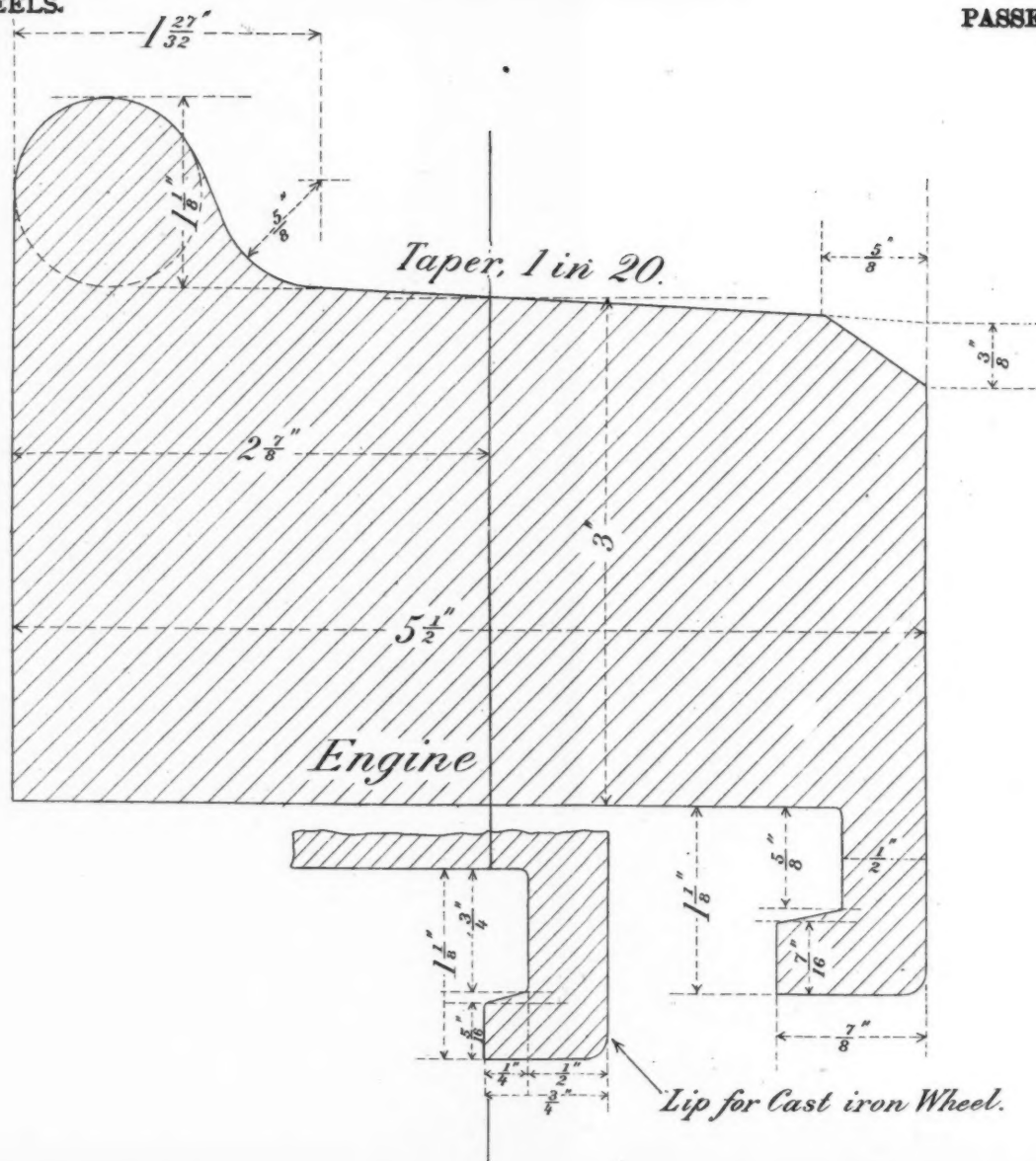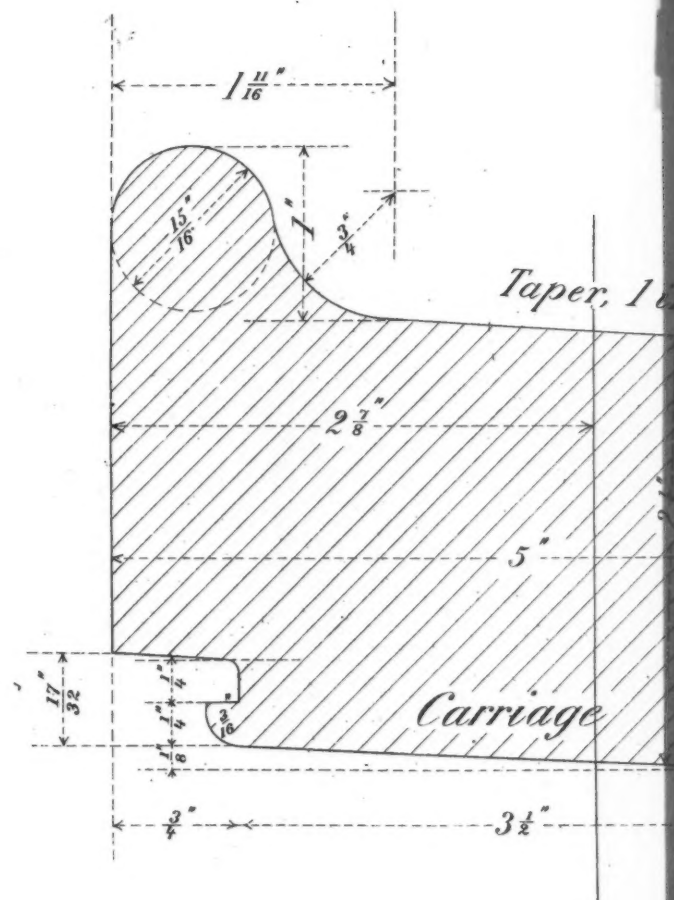
Taper, 1 in 20.

Taper, 1 i

$1\frac{27}{32}''$

$1\frac{11}{16}''$

$1\frac{1}{8}''$

$\frac{5}{8}''$

$\frac{3}{8}''$

$\frac{5}{8}''$

$\frac{3}{8}''$

$\frac{15}{16}''$

$1''$

$\frac{3}{4}''$

$5\frac{3}{4}''$

$3''$

$2\frac{7}{8}''$

$3''$

$5\frac{1}{2}''$

$2\frac{7}{8}''$

$5''$

Engine

Engine

Carriage

ding & Trailing

$\frac{17}{32}''$

$\frac{1}{4}''$

$1\frac{1}{4}''$

$\frac{3}{16}''$

$\frac{1}{8}''$

$\frac{3}{4}''$

$3\frac{1}{2}''$

$1\frac{1}{4}''$

$1\frac{5}{8}''$

$\frac{3}{4}''$

$\frac{5}{8}''$

$\frac{1}{2}''$

$\frac{5}{16}''$

$1\frac{1}{4}''$

$\frac{3}{4}''$

$\frac{5}{16}''$

$\frac{1}{4}''$

$\frac{1}{2}''$

$\frac{7}{8}''$

Lip for Cast iron Wheel.

$1\frac{1}{8}''$

$\frac{3}{4}''$

$\frac{5}{8}''$

$\frac{7}{16}''$

$\frac{1}{4}''$

$\frac{1}{2}''$

$\frac{3}{4}''$

$\frac{7}{8}''$

Lip for Cast iron Wheel.

NOTE—The distance between Tyr
is the same for the whole o

PASSENGER ENGINES.

Taper, 1 in 20

Carriage

Taper, 1 in 20

Wagon

For wheels with
3½" Spokes.

For wheels with
3" Spokes.
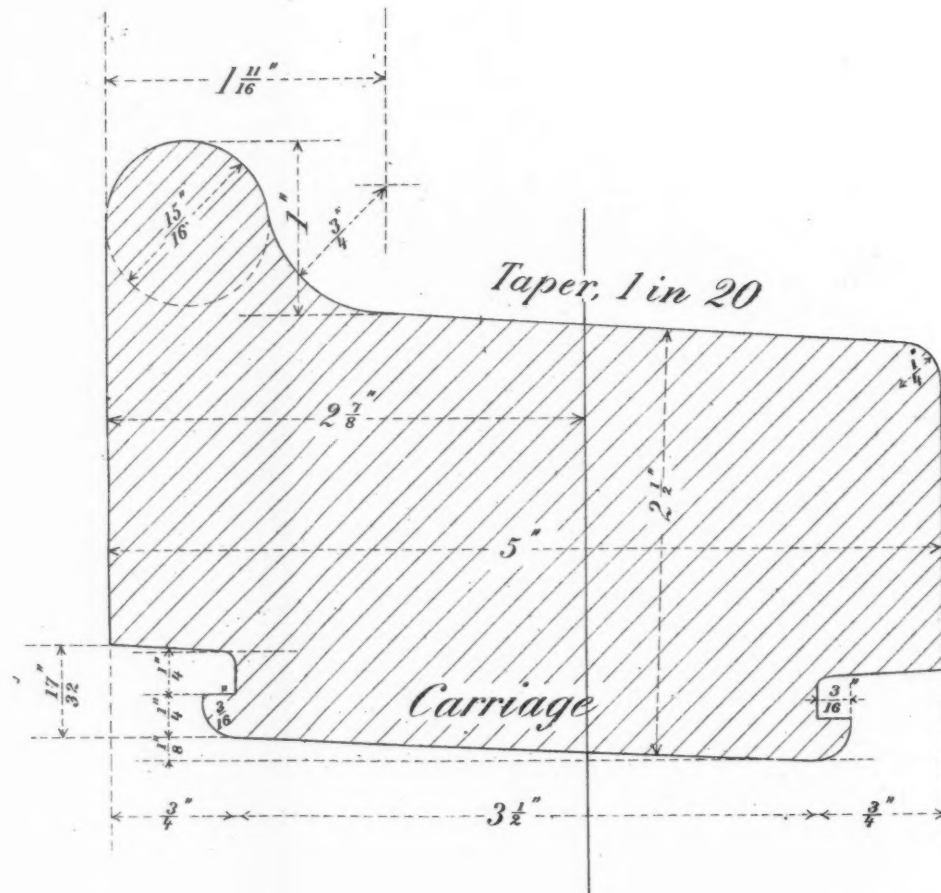
Cast iron Wheel.

NOTE—The distance between Tyres, viz. 4″—5½″
is the same for the whole of the Stock.

Section of W

their relati
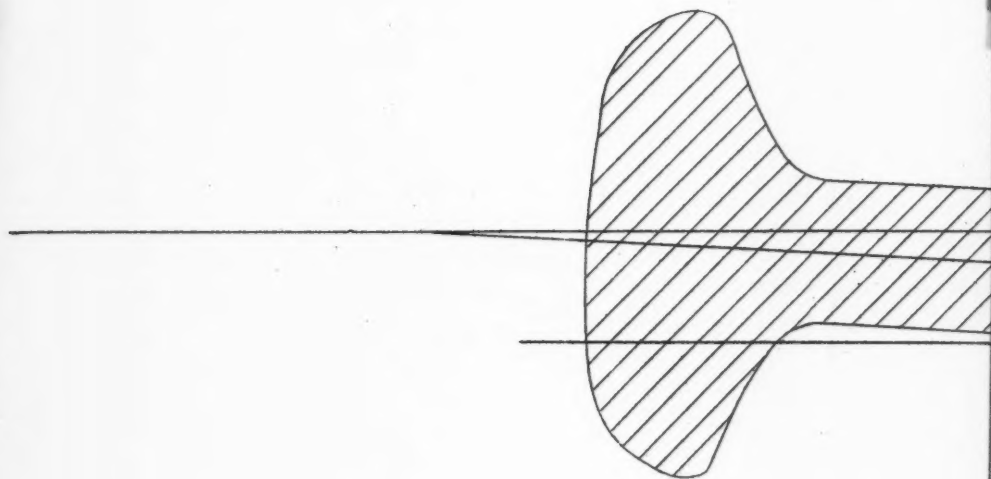
is central

...tion of Wheel, Tyre and Rail showing
their relative positions when Engine
is central between rails.

(FULL SIZE.)
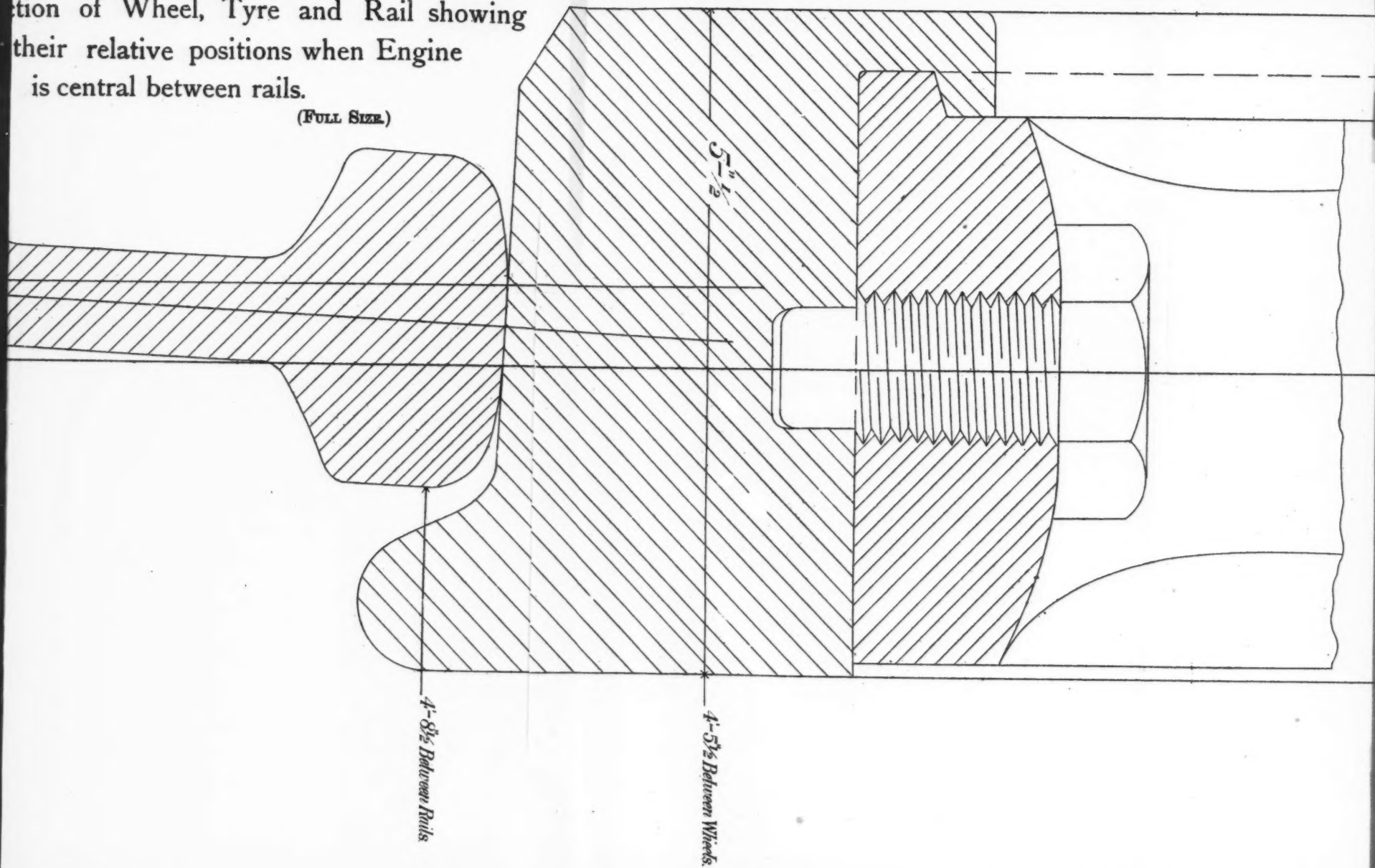
5″—½″

4′—8½″ *Between Rails.*

4′—5½″ *Between Wheels.*

5"-½"
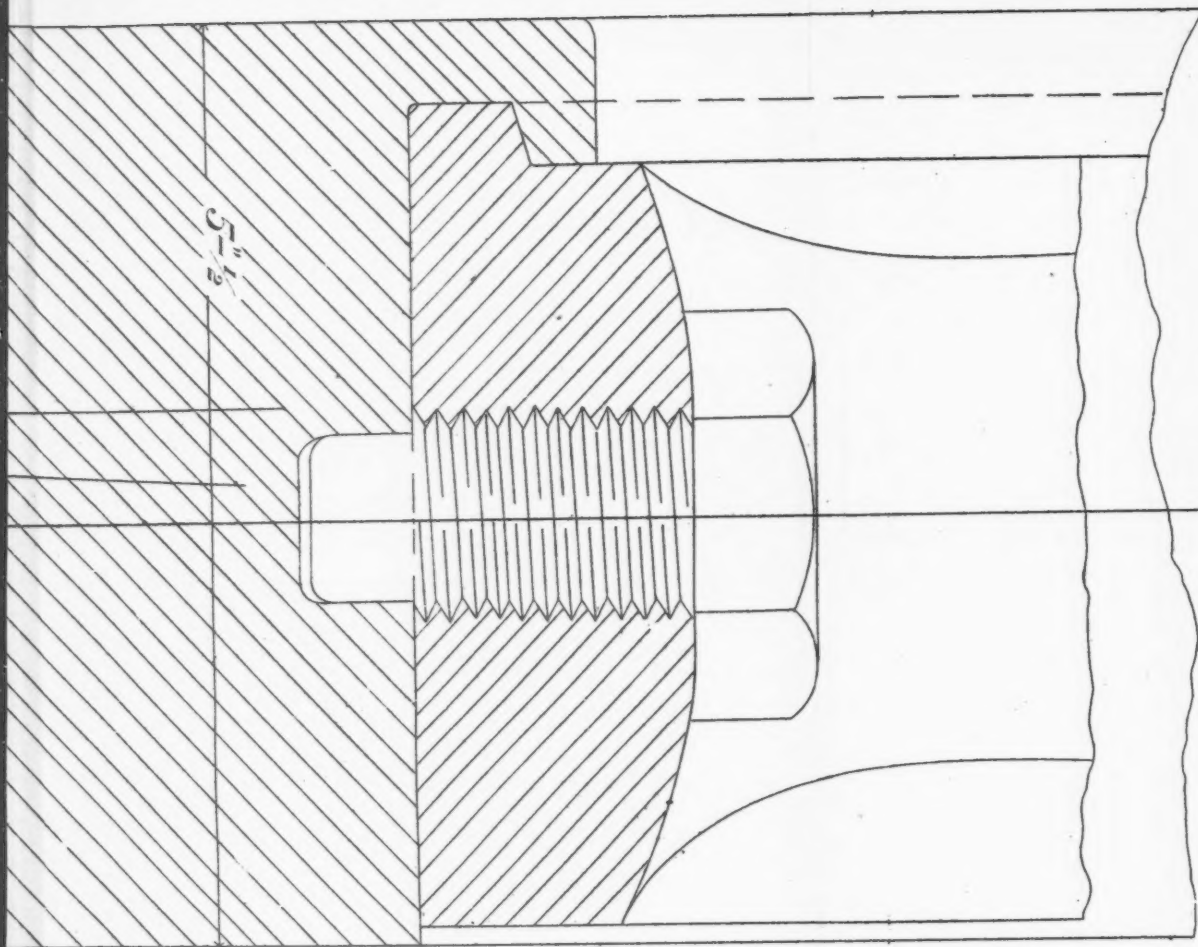
4'-5½" Between Wheels.

A limited amount of the first wear of new rails is due to abrasion. This continues until the scale is removed from the part of the head that is in contact, leaving it smooth and polished; if now the traffic is light and the metal in the rail uniform, the abrasion continues, but at a much slower rate, until the head is worn to its limit, retaining its smooth appearance; but under heavy traffic the rail shows altogether different signs of wear—signs that show that abrasion is being exceeded. And soon there are evidences of the actual failure of some part of the rail, although the surface of most of it may be still fit for a long service. It seems, then, to go without saying, that if the effect of the major cause can be reduced by increasing the area of contact to limits that will not allow the disintegration to take place, it is a matter of small concern if in so doing we somewhat, but very slightly, increase the total amount of abrasion. As far as the wheel is concerned it will only affect that portion of the tread not previously in contact; and as for the rail, it is its weakest foe.

Mr. F. W. Webb, Mech. Eng. London and North Western Railway.—I am afraid that if the rails were made as Mr. Whittemore suggests, in a very short time they would shape their own form for themselves, owing to the wear of the tires. In this country (England) we do not appear to have the same difficulty in rails wearing sideways as you have in the States, and when we decided upon the present form of the top of our bull head rail, we had templates taken over several miles of railway of rails partially worn, and we then made the top of our rail as near as possible the average of the templates we had taken in the way described. I believe we get over a good deal of the difficulty you experience by greater elevation of the outer rail on curves than you have. I know of no rule by which this can be ascertained theoretically, owing to the various speeds of trains passing over various portions of the road; but our practice has been when there are indications of wear on the side of the outer rail to elevate that rail until the wearing disappears.

The only tires we turn cylindrical are in our six-wheeled coupled engine stock, the middle wheels being turned cylindrical, so as to ease them in going round curves; the diameter being the same as the mean diameter of the cone over the center of the rail in leading and trailing wheels. The inclosed blue prints will show you our practice. (Plates LXVI and LXVII.) Our standard gauge is 4 feet 8½ inches, but in going round sharp curves we widen out the rails up to 4 feet 8¾ inches.

J. D. Hawks, M. Am. Soc. C. E.—The conclusion which Mr. D. J. Whittemore draws from his experience with steel rails is that a great many of them split, owing to the metal being strained beyond its elastic limit. On this conclusion he founds his paper, with the title given above.

If this conclusion is incorrect, then the paper is not correct.

I think the conclusion is wrong; and, consequently, think that flat topped rails, instead of being an advantage, would be a disadvantage.

Flat topped rails would not come from the mills straight, but winding. They would not be laid perfectly level on the ties, and would not stay level if they were so laid. Hence, the wear of the wheels would come on the inside or outside of top, and aggravate the evil intended to be cured. I do not think the evil is as great as Mr. Whittemore infers. We frequently change rails that have been worn down on one side of the rail on a curve to the straight line, or even to the inside of the curve, and this throws the bearing all on one side of the rail, until that side is worn down sufficiently to give an even bearing on the top. I never have noticed any rails so used that have split and cracked.

I have put new rails in track when the ends showed splits, and have watched them carefully, in order to see how long they would wear before the splits fully developed, and sometimes it would be years before a split could be noticed, except by a person who knew that the rail was split. I have also left rails in track for years after the rail showed a decided split. I do not recommend such a course, however, and I now have all split rails removed every fall from track, as there is no tendency, of course, in split rails to mend themselves, and I do not consider it worth while to see the length of time they will wear, when an accident may result from leaving them in a little too long.

Splits can frequently be detected by black spots or black streaks along the head of the rail before the split has opened. I have cut a great many rails showing these black streaks, and have always found the split that I was looking for. I have also frequently found splits that I was not looking for, while cutting rails, but never have found one yet that I did not believe resulted from a defect in the ingot, and not from over-straining the rail.

Splits develop more frequently in the ends of the rail than in the middle, but are common enough in the middle. Why should a split show in one part of a rail and not in the whole length of it, if the split came from over-straining the rail, and not from a mechanical defect? I have frequently cut off the end of a rail on account of a split, and worn out the remainder of the rail in a track without any further trouble from splitting. Of course, the end of the rail gets the heaviest blow and the hardest usage; but this is not the reason why splits show more frequently at the end of a rail than in the middle. The real reason is that the end of the rail is nearer the end of the ingot. The heavy blows on the ends of soft or "pewter" rails, that we had so much trouble with a few years ago, did not split the ends, even when the ends were worn or battered down half an inch. Of course, the blow under these circumstances was very much more severe than it ever is in a properly kept up track.

It is frequently the case that rails are split in the main track and taken out and put into sidings or switching tracks with half the heads

split off, and will stand all right for a long time if it is the outside half of the head that is gone.

There is no part of engineering where more care is needed in drawing conclusions than in track work. Only last week the Vice-President of a large steel rail mill was telling me that a western road was very much pleased over an experiment they had tried of putting long six-bolt splices on some steel rail that was considerably battered at the joints. The result of the experiment was that the joints got very much better, and the conclusion was that it was owing to the long splices. While I am an advocate of the long splice, I still was under the necessity of relating a little experience of my own, where a long strip of Troy steel, that had been battered so much at the joints that I feared the whole lot of it would have to come out and be condemned as soft rail, improved from year to year, and is very much better at the joints now than it was five years ago; and still it has on it the four-hole short splices with which it was laid.

Our sales of scrap steel from 2 100 miles of steel rail track average about 900 tons per year, and a large part of this comes from worn out steel rail frogs and ends from rails which are cut off by our rail-saw.

I attach our steel-rail report for the last four years, showing the number of broken, split and worn out rails removed from track. I know it is not customary to give the makers' names in such a report, but do not think there can be any fault found with it in this case. (Tables Nos. 1 and 2.)

It will be noticed that the record for steel made during the last four years is very good indeed. The record is deceptive, in some respects, without explanation. Many of the breaks in the older rails were caused by punching bolt-holes. The record of the bruised or battered rails would have been very much larger, except for the fact that long pieces of track laid with the "pewter" rails showed up in such bad shape that they were taken up, and the rails sent to branches or used in sidings after having been in use only a few months on main line.

We received the last of the soft rails in 1884, and the report of rails taken out of track, of recent rails, is very good indeed, and shows no increase in the tendency of rails to split on account of over-straining of the metal, as all rails laid since 1884, until this year, are 65 pounds per yard. Our standard is now 80 pounds per yard, and I shall be disappointed if this heavy rail does not show fewer bruises and fewer broken rails than the 60 and 65 pound rail, besides giving us a much better riding track, and one that can be maintained at much less expense.

We get considerable wear out of defective rails after they have broken at the end or split at the end, as we saw off such rails and use them on branches. Of course, it costs money to do this, and I would very much prefer that they would not split, or break, or bruise, but have very little fault to find with such a record as that of the last four years.

I think the rail-makers are agreed that they can now make a rail from 65 pounds upwards, of any of the recent shapes, that will carry any traffic in this country, without any undue tendency to split or crush. I do not think that the present discussion in relation to flat top rails should be construed as showing a tendency to give the rail men any more advantages than they have at present. We have had a great deal of trouble, of course, from poor rails, but I think the railroads are more responsible for a good share of this trouble than the rail-makers, and from my experience with rails during the last few years, I think we have every reason to suppose that the worst of our trouble with poor rails is over.

TABLE No. 1.

STEEL RAILS MICHIGAN CENTRAL RAILROAD.

BRAND.	Number Rails Received.	Broken.	Bruised.	Split.	No Fault.	Total.	Number Rails in Track April 1st, 1889.	REMARKS.
Cammell, Sheffield, 1885..	7 002	23	..	5	..	28	6 974	
" " 1888..	3 494	..	..	..	..	..	3 494	
Edgar Thomson, 1885..	1 847	3	..	..	..	3	1 844	
" " 1887..	36 438	39	..	7	2	48	36 390	(No fault.) Caused by broken wheel.
N. C. R. M., 1885..	14 359	13	..	8	..	21	14 338	
" 1886..	1 756	1	..	1	..	2	1 754	
" 1888..	26 872	4	..	1	2	7	26 865	(No fault.) Caused by engine slipping.
Barrow, 1886..	6 975	1	..	2	..	3	6 972	
" 1887..	5 240	4	..	9	..	13	5 227	
Scranton, 1886..	20 440	3	..	9	..	12	20 428	
Totals.........	124 423	91	..	42	4	137	124 286	

Mr. WHITTEMORE.—Mr. Hawks states my position quite correctly, in that rails split and fail through straining them beyond their limit of elasticity. He states further, that, if this position is incorrect, then my paper is incorrect, and then proceeds to prove to his own satisfaction that it is so, knocking me out in the first round, and now the question in my mind is whether his blow is not delivered below the belt. I think it is.

Mr. Hawks will not contend for one moment that rails with all the defects he mentions will disintegrate and fly to pieces without being subject to extraneous strains, and these strains must be of sufficient magnitude to exceed the limit of elasticity, be the rail defective or not so far as manufacture is concerned.   These strains will search out and

BRAND.	Tons in Track June 1st, 1884.	Received, 1884.	TAKEN OUT DURING YEAR 1884.					Tons in Track Jany. 1st, 1885.	Received, 1885.	Broken
			Broken.	Bruised.	Split.	Worn Out.	No Fault.			
John Brown..	8 146	......	4½	7½	2	½	....	8 131½	......	16
Cammell Sheffield	29 082	2 510	3	8	4	....	....	31 577	2 002	3½
Landore	5 218	......	....	1	....	....	....	5 217	......	2½
C. I. & Co	2 446	......	4½	20	12½	½	....	2 409	......	12
Fox & Co.	4 923	......	2½	6	4½	....	....	4 910	......	6½
Griswold	3 467	......	3	11¾	4½	1½	....	3 446¾	......	9½
Edgar Thomson	10 395	......	....	37½	....	....	.. ..	10 357½	528	8
Lackawanna Iron and Coal Co.	7 053	......	....	1	....	....	....	7 051	......	1½
C. R. M. Co.	11 006	......	3½	7	1½	....	....	10 994½	......	21
M. C. Besseges	1 399	......	....	......	....	....	....	1 399	......	½
N. C. R. M. Co	1 291	......	....	......	....	....	....	1 290½	4 121	1
Joliet	8 457	6 491	6½	3½	2	....	....	14 936½	......	15
Troy Steel	10 964	......	41½	10½	13	....	....	10 898½	......	4½
A. F. Creusot	1 272	......	3½	......	½	....	....	1 268½	......	24
C III	136	......	¼	1	½	....	....	133¼	......	½
B. B. & Dixon	1 007	......	¼	......	....	....	....	1 006¾	......	8½
Bessemer Steel.	27	......	....	....	....	....	....	27	......	....
No brand	2 240	......	....	.. ..	...	....	....	2 240	......	2¾
S. S. Bautin & Co	3	......	....	......	....	....	....	3	......	....
Barrow	930	......	½	....	....	....	....	929½	......	14½
Saunders Bros	1 015	......	....	......	....	....	....	1 015	......	....
Dowlas	9 826	......	12	1½	8	¼	....	9 804	......	22½
A. F. Ferremore	606	......	¼	......	....	....	....	605½	......	1¾
B. V. & Co	761	......	¼	......	....	....	....	760¼	......	17½
West Cumberland	15	......	....	......	....	....	....	15	......	....
Scranton	......	......	....	......	....	....	....	......	......	....
Totals	121 685	9 001	86	116½	53½	2½	....	130 427½	6 651	394½

Received, 1885.	TAKEN OUT DURING 1885.					Tons in Track Jany. 1st, 1886.	Received, 1886.	TAKEN OUT DURING 1886.					Tons in Track Jany. 1st, 1887.
	Broken.	Bruised.	Split.	Worn Out.	No Fault.			Broken.	Bruised.	Split.	Worn Out.	No Fault.	
......	16	6	4	½	1	8 108¾	......	10½	4	2½	....	....	8 086¾
2 002	3½	74	16	½	6½	33 478½	......	20½	25	4½	....	3	33 424½
......	2¼	5	....	¼	....	5 209½	......	1½	3½	....	¼	....	5 204
......	12	32	20	2½	2	2 340½	......	8	16½	12½	....	....	2 309½
......	6¾	13	7½	½	1½	4 880½	......	5½	9	9	....	....	4 857
......	2½	41	7	1½	½	3 386¾	......	8¼	16	8½	½	....	3 353½
528	8	122	13	....	2	10 740½	......	6	59	4½	....	....	10 671
......	1½	½	3½	½	....	7 045¾	......	2½	1½	2½	....	....	7 039½
......	21	18	12	....	....	10 943½	......	19	11	15½	....	....	10 897½
......	½	2	¼	....	....	1 396½	......	1¾	2½	1	....	....	1 391
4 121	1	½	....	....	½	5 409	499	3	¼	....	....	....	5 905½
......	15	65	18	1	....	14 836½	......	15½	4½	6½	¼	....	14 810
......	4½	13	10	....	....	10 871½	......	2½	78	10	....	....	10 780¾
......	24	4	14¾	....	....	1 225½	......	26	3	3½	....	....	1 193½
......	½	2½	....	½	....	130½	......	1	1¾	¼	½	....	127
......	8½	½	....	....	....	997½	......	7	......	¼	....	....	990½
......	....	....	....	....	....	27	......	....	....	....	....	....	27
......	2¾	......	....	....	....	2 237½	......	1	......	....	....	....	2 236½
......	....	......	....	....	....	3	......	....	......	....	....	....	3
......	14¼	¼	1½	....	....	913¾	2 000	9	¼	¼	....	....	2 904½
......	¼	......	....	....	....	1 014¼	......	....	......	....	....	....	1 014¾
......	224	76	107½	....	½	9 396	......	167	33½	60½	....	....	9 135½
......	1¾	......	....	....	....	604	......	3	......	....	....	....	601
......	17¼	......	1	....	....	742½	......	8½	......	¼	....	....	733½
......	....	......	....	....	....	15	......	....	......	....	....	....	15
......	....	......	....	....	....	....	6 011	....	......	....	....	....	6 011
6 651	394½	475½	235½	8¾	15½	135 948½	8 510	327¼	268½	▲142½▲	1¼	3	143 716¼

AL RAILROAD COMPANY.

Tons in Track Jany. 1st, 1887.	Received, 1887.	TAKEN OUT DURING 1887.					Tons in Track Jany. 1st, 1888.	Received, 1888.	TAKEN OUT DURING 1888.				
		Broken.	Bruised.	Split.	Worn Out.	No Fault.			Broken.	Bruised.	Split.	Worn Out.	No Fault.
8 086½	......	12	¼	½	....	....	8 073½	......	36½	25½	24	7½	2
33 424½	......	40½	16½	8½	....	1	33 358½	1 000	34	51	49¾	½	....
5 204	......	1½	1	¼	....	....	5 201½	......	8½	3½	5¼	....	¼
2 303½	......	7½	13	7½	2	....	2 273½	......	33	37½	35½	2½	¼
4 857	......	2	4¼	4½	....	....	4 846½	......	17½	19	86	....	¼
3 353½	......	9½	14	5	....	....	3 325½	......	25	25½	53	....	4
10 671	10 596	4½	5½	¾	....	....	21 256½	......	20	30	14	....	¼
7 039½	......	3	½	2	....	....	7 034½	......	8½	10½	31½	....	....
10 897½	......	10	65½	39½	....	....	10 788½	......	42½	39½	82½	2½	¼
1 391	......	¼	½	½	....	....	1 389½	......	2½	¾	4¼	....	....
5 905½	......	1½	¼	¼	....	....	5 903	7 730	11	5½	15	....	....
14 810	......	9¼	24	3½	....	....	14 773½	......	74	25	225	....	....
10 780½	......	3½	30	1¼	....	....	10 745½	......	4	21	3½	....	....
1 193½	......	1½	½	2	....	....	1 189½	......	15	2	37½	....	....
127	......	¼	1	....	....	....	125	......	1½	1½	4¼	½	....
990½	......	1½	......	1	....	....	987½	......	4½	2½	2½	....	....
27	......	....	......	....	....	....	27	......	....	......	....	....	....
2 236½	......	1½	......	¼	....	....	2 234½	......	2½	5¼	¾	½	....
3	......	....	......	....	....	....	3	......	....	......	....	....	....
2 904½	1 500	1½	1¼	¾	....	....	4 400½	......	2½	5½	4½	....	1½
1 014½	......	....	......	....	....	....	1 014½	......	2½	2½	2½	....	¼
9 135½	......	7½	42½	36	....	1½	9 047½	......	21	42	125	....	5
601	......	½	......	....	....	....	600½	......	1	½	5½	....	....
733½	......	....	......	....	....	....	733½	......	....	½	½	....	....
15	......	....	......	....	....	....	15	......	....	......	....	....	....
6 011	......	¼	......	¾	....	....	6 009¾	......	....	......	1¾	....	....
143 716½	12 096	119¼	221½	108½	2	2½	155 358½	8 730	366½	353¾	814	14¼	14¼

No Fault.	Tons in Track Jany. 1st, 1887.	Received, 1887.	TAKEN OUT DURING 1887.					Tons in Track Jany. 1st, 1888.	Received, 1888.	TAKEN	
			Broken.	Bruised.	Split.	Worn Out.	No Fault.			Broken.	Bruised.
....	8 086¾	......	12	½	¾	....	....	8 073½	......	36½	25½
3	33 424¾	......	40½	16½	8¼	....	1	33 358½	1 000	34	51
....	5 204	......	1½	1	¼	....	....	5 201½	......	8½	3½
....	2 303½	......	7¾	13	7¼	2	....	2 273½	......	33	37½
....	4 857	......	2	4½	4¼	....	....	4 846½	......	17½	19
....	3 353½	......	9½	14	5	....	....	3 325½	......	25	25½
....	10 671	10 596	4½	5½	¾	....	....	21 256½	......	20	30
....	7 039½	......	3	½	2	....	....	7 034½	......	8½	10½
....	10 897½	......	10	65½	39½	....	....	10 788½	.....	42½	39½
....	1 391	......	½	½	½	....	....	1 389½	......	2½	¼
....	5 905½	......	1½	¼	¼	....	....	5 903	7 730	11	5½
....	14 810	......	9¼	24	3¾	....	....	14 773½	......	74	25
....	10 780¾	......	3¼	30	1½	....	....	10 745¾	......	4	21
....	1 193½	......	1¼	½	2	....	....	1 189½	......	15	2
....	127	......	½	1	....	....	....	125½	......	1½	1½
....	990½	......	1½	......	1	....	....	987½	......	4½	2½
....	27	......	....	......	....	....	....	27	......	.....	.....
....	2 236½	......	1½	......	¼	....	....	2 234½	......	2½	5½
....	3	......	....	......	....	....	....	3	......	.....	.....
....	2 904½	1 500	1½	1¼	¾	....	....	4 400¾	......	2½	5½
....	1 014¾	......	....	......	....	....	....	1 014¾	......	2½	¾
....	9 135½	......	7½	42½	36	....	1½	9 047¾	......	21	42
....	601	......	½	......	....	....	....	600½	......	1	¼
....	733½	......	....	......	....	....	....	733½	......	....	¼
....	15	......	....	......	....	....	....	15	......	....	.....
....	6 011	......	½	......	¾	....	....	6 009½	......	....	.....
3	143 716¼	12 096	119¼	221½	108½	2	2½	155 358½	8 730	366½	353½

	TAKEN OUT DURING 1888.				Tons in Track Jany. 1st, 1889.	RECAPITULATION.					
n.	Bruised.	Split.	Worn Out.	No Fault.		Broken.	Bruised.	Split.	Worn Out.	No Fault.	Total Tons.
	25½	24	7½	. 2	7 978½	79½	43½	33½	8¾	3	167½
	51	49¾	½	....	34 223	101½	174½	82½	1¼	10½	371
	3½	5½	....	....	5 184½	13½	13½	5½	¼	....	33¾
	37½	35½	2½	¼	2 165	65	118½	87½	7¾	2½	281
	19	86	¾	¼	4 723	34	51½	111¾	1¼	2	200
	25½	53	....	4	3 217½	55	108½	77¾	3½	4¾	249½
	30	14	....	½	21 191½	38½	254	32¼	....	2½	327½
	10½	31½	....	....	6 984½	15	13½	40	¼	....	68½
	39½	82½	2½	¼	10 621½	95½	141½	145½	2¼	¼	384½
	½	4½	....	....	1 382½	4½	6	5½	....	....	16¾
	5½	15	....	....	13 601½	16¾	6½	15	....	½	39½
	25	225	....	....	14 449½	120½	121¾	254½	1½	½	498¾
	21	3½	....	....	10 717½	55¾	152¾	38	....	....	246¾
	2	37½	½	....	1 135	69¾	9½	57¼	....	....	137
	1½	4¼	....	....	117¼	4	7½	5¼	1¼	....	18½
	2½	2½	....	....	978½	22	3	3½	....	....	28¾
		....	....	....	27	....	....	....	....	....	....
	5½	¾	½	....	2 224¾	8	5½	1	....	½	15½
	....	....	....	....	3	....	....	....	....	....	....
	5½	4½	....	1¾	4 386½	27½	7½	6½	....	1¾	43½
	2½	2½	....	....	1 009½	2½	....	2½	....	....	5½
	42	125	....	5	8 854½	431½	195½	336½	¼	7	971½
	¼	5½	....	....	594½	6½	4	5¼	....	....	11¼
	½	½	....	....	732½	26½	....	z	....	....	28½
		....	....	....	15	....	....	....	....	....	....
	......	1¾	....	....	6 008	½	......	2½	....	....	3
	353½	814	14¼	14¼	162 526	1 293½	1 435½	1 353½	28¾	35½	4 147

find the weakest part of the rail, and the effect will there be first apparent.

The point I make is that in no way other than by corrosion, does material, good or bad, fail, except through strains beyond the limit of elasticity, and I expressly state in my paper that, while good material will render greater service by being correctly formed, poor material will also give better service for the same reason.

While I must admit that the early failure of many of our rails can be attributed in a great measure to faulty manufacture, I seek to call the attention of our members to a fault of design, which, when corrected, will, as I believe, add materially to the service of both good and faulty material.   Good material correctly formed can only be secured through care in manufacture and inspection, and the rails should then be laid in their position as nearly correct as practicable.   This can be done, and when done the objections raised against the flat headed rail will be in a great measure, if not entirely, overcome, provided we can have cylindrical wheels to run upon them.

M. L. LE ROND, C. E. (Ingénieur des Ponts et Chaussées).—Mr. Whittemore's paper is highly interesting and expresses novel ideas on a problem which may be considered as vital for the near future of railroads. He points to the frightful overloading of the metal of rails and tires, and to the ever-growing danger concealed in such a practice.   An arrangement which shall reduce the strains in the metal to a reasonable rate beneath the elastic limit, will avoid fearful disasters which must fatally happen otherwise before this century is ended.   And none of the advantages claimed by the author of the paper for cylindrical wheels traveling on flat topped rails, seem to be overestimated.

The values given in the table, page 145, show that with Mr. Whittemore's arrangement, the weight on wheels can be safely increased to almost any extent, providing that the width of the flat top and cylinder shall be correspondingly increased.   And is not this fact one of common evidence, viz., that the way to reduce rotary friction on a yielding surface is to increase the width of the tread of wheels?

On a solid road-bed narrow treaded wheels may do, but not on a soft or damp soil ; country carts must have wheels provided with a broad tread, or they will be soon mired.

On railroads, with the weights now in use, both rail and wheel, or tire, must yield, increasing the resistance of trains, as well as crushing the metal.

So that the flat topped rail and cylindrical wheel, being the safest, are at the same time the best arrangement to secure the least frictional resistance on tangents.

It is easy to see that it generally reduces, also, the friction on curves.

In the case of flat topped rails and cylindrical wheels the frictional resistance will be $(R-R^1)\ \alpha f P$

Where R and R^1 are the radii of the outer and inner rails,

a the angle between two radial positions of the axle,

f the co-efficient of sliding friction,

P the weight on the axle.

On the other hand, in the case of usual rails and coned wheels, the inner traveling on its greatest, the outer on its least diameter, the friction will be for the same length of curve traveled on,

$$(r^1 - r)\ w f P + (R - R^1)\ a f P$$

Where R, R^1, f, a, P have the same meaning and value as above,

r^1 is the greater wheel radius (inner),

r is the least wheel radius (outer),

w the revolution of the axle corresponding to the length traveled on.

It appears therefrom that, as stated, the resistance is greater in the case of coned wheels, and the value of the excess is

$$(r^1 - r)\ w f$$

Which is reduced to zero, as it ought to be, when $r^1 = r$, or in the case of cylindrical wheels.

The adoption of Mr. Whittemore's ideas in American railroad practice will, therefore, be an evident progress.

On European, viz., on French railways, the advantages might be less.
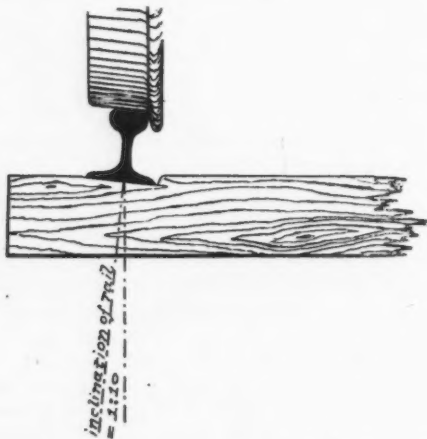
It is a custom on our roads to notch down the rails on the ties so that their web is not vertical, but inclined, from bottom to top, toward the inside of the track ; the inclination of the web is one in ten (see Figure).

This disposal has some advantages, to prevent, on tangents, the rails from spreading, and, on curves, from turning over.

The coned wheel has thus its tread surface sensibly parallel to the rail top, and the bearing area is not as small as in American practice.

The coned surface is then properly fitted to suit the inclined top of rails, and this is a reason which forbids, on French roads, the use of cylindrical wheels, till the vertically laid rail is adopted.

The coned wheel, unfit on American roads, seems not, therefore, to be as improper on ours ; although, if a proper fastening of rails be secured, the adoption of Mr. Whittemore's ideas, with vertically laid rails, would evidently simplify some of the most intricate problems now involved in railway construction and maintenance.

As for Brunel's double web rail, though it may seem theoretically commendable, it paid no good service, some years ago, on the "Chemin de fer du Midi," where it was tried as "rail Barlow." The iron rails of that pattern had to be all taken out after a few years.

CHARLES BLACKWELL, M. Am. Soc. C. E.—In regard to best form for rail heads, I believe that the excessive weight now imposed on engine and freight car wheels, renders it necessary to meet the evil by adding to the utmost extent possible to the areas in contact; and I fully endorse the proposition to make the rail heads entirely flat, with a $\frac{1}{8}$ or $\frac{5}{16}$ top radius. But in conjunction with this, the "rail path" or "tread" of all wheels must be made parallel.

C. FRANK ALLEN, M. Am. Soc. C. E.—In considering rails and wheels and their preparation for the scrap heap, and in considering the proper form of section of rail, it seems to me that for the immediate present we should look closely to the form as affecting the quality of rails (or wheels), and I believe that emphasis should be laid upon the fact (recognized by Mr. Whittemore in his paper) that "all ills the rail is heir to cannot be attributed to the error of its curved top." The tendency at present seems to be in the direction of heavier sections as a remedy for the unsatisfactory wear of rails. Is it certain that this is a step in the right direction ? What can we gather from past experience upon this point ? Quoting from the paper of Robert W. Hunt, M. Am. Soc. C. E., read before the American Institute of Mining Engineers: "One of the most prominent chief engineers of the country said to me not long ago that he supposed his road would lay 80-pound rails next year, but he was at a loss what section to adopt, for if their 80's gave as much poorer service as compared with their 65's, as the latter had in relation to their old 60's, he guessed they would have to adopt a 90-pound rail for the following year. This states it broadly, but it is a generally admitted fact that the increased sections have as a rule been disappointing in their wear."

It would seem possible that the increased size was obtained at the cost of the "physical hardness" of the metal, the larger section rendering proper rolling difficult or impracticable.

In the case of locomotive tires the discussions of the Western Railroad Club, not long since, established beyond a reasonable doubt the fact that 3-inch tires were superior in wearing quality to 4-inch tires; and the principle involved would appear to be no different in the two cases of tires and rails. All the above evidence certainly is not favorable to large sections for tires or rails of steel.

History often repeats itself, and in the case of iron rails it appears that a similar unsatisfactory experience with heavy iron rails was had many years ago. Quoting from Colburn and Holley on "Permanent Way of Railroads," published 1858: "The 45-pound rails made in 1837 for the Philadelphia and Reading Railroad have stood a wonderful wear. The 64 and 68-pound rails since laid down in their place have gone to pieces with less than one-third the same wear."

Again: "In 1854 rails of 85 to 100 pounds were considered by English engineers to be the best. Since that time it is found in the Eastern counties line that the 95-pound rails made the worst road, were less durable, and in course of time became the most dangerous, as compared with 75-pound rails."

"The London and Northwestern officers report more failures with the 82-pound rails than with the former 56-pound rails."

"The New York and Erie Road has had rails of 58, 60, 63, 65, 68, 72 and 75 pounds laid down, in place of 56-pound rails, the heavier iron almost invariably proving inferior."

The experience of a number of other roads noted was in the same line, and opinion seemed to have become general in favor of 60 to 70 pounds, rather than from 85 pounds upward.

One experienced buyer stated "that the only good way to get good rails was to contract for 85 pounds per yard, and to then arrange with the manufacturer to supply a better quality, of 75 pounds per yard, for the same gross sum." Isn't it possible that the same rule will hold good for steel? It seems to me that better quality is what is needed, and that our energies can best be directed to that end at present.

It is not my purpose to discuss the correctness of the formulas and results used by Mr. Whittemore. The status of affairs seems to me to be this: whether or not we have thus far kept within the elastic limit, there can be little doubt that weights of rolling stock still tend to increase, and it seems probable to-day that this increase will be limited finally by the safe carrying power of the rail, and we shall be at last brought to decide what form of section will safely carry the heaviest load. Improving the quality of the steel will help us and may delay the issue for a time, but the question is going to be not altogether whether the elastic limit is now exceeded, but whether it will be exceeded sooner upon a rail with a curved or with a flat top. It seems to me, too, that when we are upon the point of exceeding the elastic limit on the tops of the rails, we shall probably have passed the elastic limit at the rail corners, for

the resultant of the vertical and horizontal forces acting on the rail of
the curve would almost certainly be greater than the vertical force alone
on the rail of the tangent; and the area of bearing surface ought not to
be less.   I am not of the opinion that the qustion of flat topped rails
can be altogether settled upon paper.   There are many points involved.
What will be the effect upon traction—upon rolling friction ?   Can the
rail be maintained flat ?   The question, it seems to me, is whether the
expectation of benefit from the use of flat topped rails is sufficient to
warrant a thorough trial being made, and it seems to me that this much
at least Mr. Whittemore has shown to be the case in his paper.

C. L. STROBEL, M. Am. Soc. C. E.—The subject of the relations of
the sections of railway wheels and rails is of the greatest importance.
Mr. Whittemore has taken exception to some of the Committee's con-
clusions as contained in its Preliminary Report, and has very ably sup-
ported his views.

Unless all mechanical practice and theory in the past are wrong, a
point contact between bearing surfaces is more destructive than a line
contact, and the latter is more so than a surface contact.   Points and
lines in this sense are, of course, surfaces also, only they are such of
very small area.   A line may be considered a succession of points placed
side by side.

In theoretical investigations of this subject, it has usually been ad-
mitted that the form of the surfaces in contact, outside of the area of
contact, has an influence upon the resistance of the parts in contact; but
it has never before been claimed, so far as I know, that this influence
can be so great as to make the wear less for a point contact than for a
line contact.   Thus cannon ball rollers, when used under the movable end
of a bridge, have never been supposed to be the equivalent of cylindrical
rollers, roller for roller; for example, a 3-inch ball has not been used in
the place of a cylindrical roller 3 inches in diameter and say 2 feet in
length.   If this substitution had been made the result would undoubt-
edly have proved disastrous.

The loads which are applied upon the wheels of cars and engines
may not be excessive for a point contact, but Mr. Whittemore has pro-
duced strong evidence that they are.

A number of writers have endeavored to find a theoretical solution for
the problem of wheel contact.   They have been successful only by
assuming certain approximations to the actual conditions.   Professor
Grashof's formulas are among the best known, and, in the absence of
something better, have been extensively used to determine the permis-
sible loads for bridge rollers.   The values obtained cannot be assumed
as final, but they are at least serviceable as "an educator of the judg-
ment," as Mr. Whittemore puts it.   Even if it were possible to solve
the problem by theory absolutely, there would still remain the indeter-
minable elements of impact and unevenness of road-bed, which more or
less invalidate all calculations.

In the light of all the information we have upon the subject, however, the conclusion seems warranted that our present practice overtaxes both wheel and rail.

If the elastic limit is exceeded the metal flows, the molecules re-arranging themselves in conformity with the new conditions. This occurs more readily in a homogeneous metal like steel than in a fibrous metal like wrought-iron, and by continued action of this kind ultimate disintegration takes place. The motion of the wheel over the rail is particularly favorable for such destructive action in the rail.

The increase in the loading of wheels, which has been going on for some time, is not likely to have reached its limit yet. Metallic cars, of better construction, lighter weight and greater capacity than the present rolling stock, will be introduced, and the tendency will probably continue to put more weight upon the wheels. This may require a radical reconstruction of the railroads, and while this is somewhat startling to contemplate, it is a change such as takes place in manufacturing concerns in comparatively short intervals, namely, the substitution of a new plant for an old one, when it has been found that better results can be obtained by different machinery or methods. There is no reason why it can be expected that railroads will be exempt from such changes.

I think the contact between rail and wheel should be a line contact, as Mr. Whittemore proposes, but undoubtedly a slight tendency towards rounding the rail top will exist, due to abrasion from worn wheels, which will be more or less hollow in the tread. While, therefore, the theoretical condition of line contact cannot be absolutely maintained, there is no reason why we should not make as close an approximation to it as possible. Whether the rail-top should be an inclined surface or horizontal, and the wheel be conical or cylindrical, may be open to question. The rail could be inclined inward, as is done to some extent abroad, the gain from which would be that the flanges have a smaller duty to perform in preventing derailment for track on straight line. This would result in less flange wear and smoother running. The different diameters of the tread of conical wheels would, however, cause sliding on the rail, owing to the different velocities of the peripheries, and this will result in greater abrasion and friction. The Committee has found that flange wear with our present practice is not excessive, and in view of this, cylindrical wheels and upright rails, as proposed by Mr. Whittemore, may be the better plan. In this case there would be no sliding of surface for track on straight line, excepting for flanges. Experiments, however, would seem necessary, to decide the question satisfactorily as to which plan is preferable.

I am inclined to attach considerable importance to a change in rail section, only lightly touched upon by Mr. Whittemore in the conclusion of his paper. For present and prospective rail loads, the question arises whether we have not outgrown the old T-rail, and ought to

3"

38"

15°%

2½"

1"/₁₆"

3' 2"

1' 4"
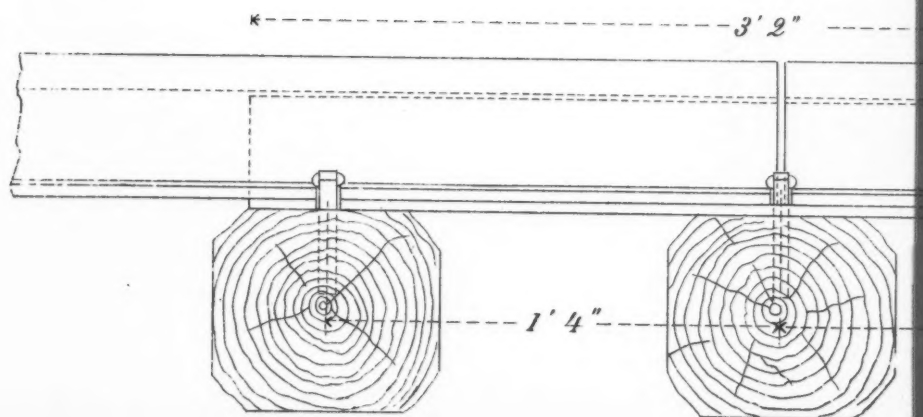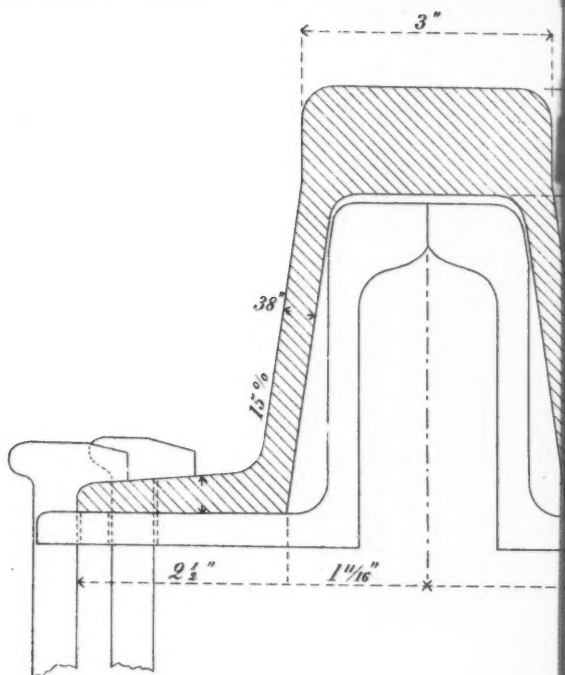
No. 1, WEIGHT 85 lbs.
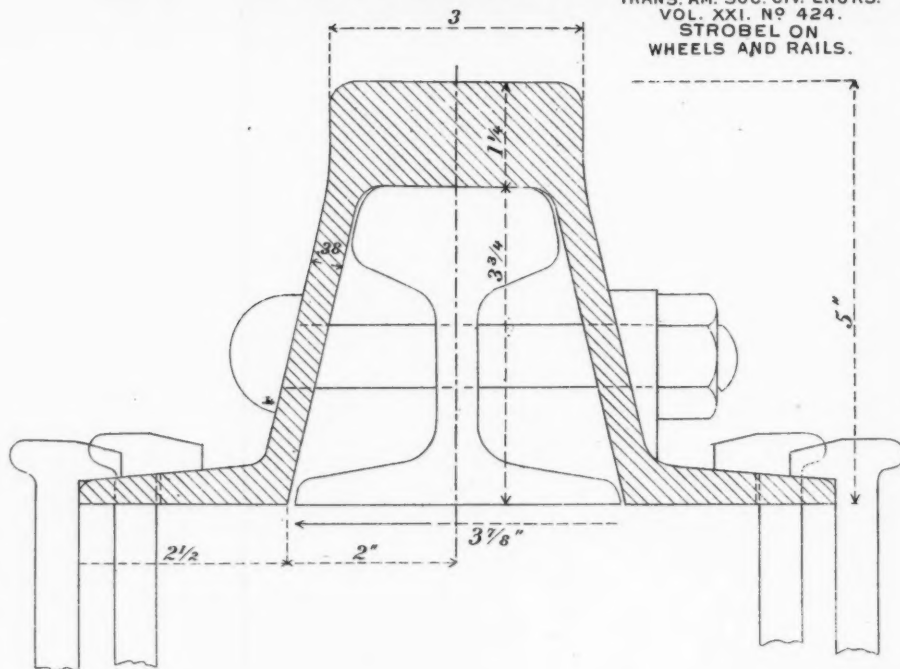
No. 2, WEIGHT 85 lbs.
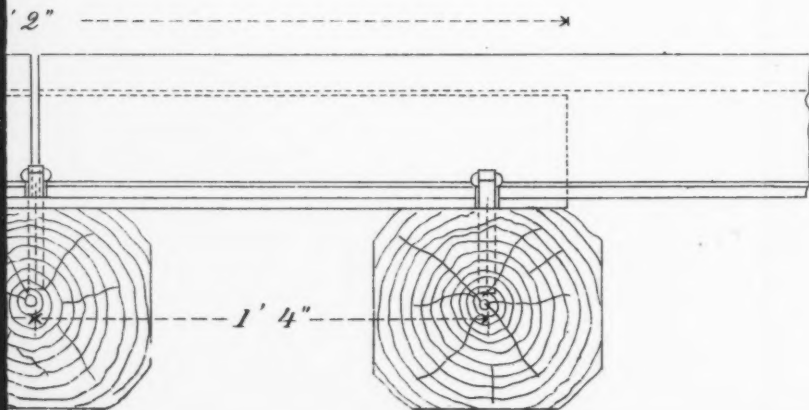
adopt the bridge rail of the type used on a number of roads in the early days of railroad construction.   This rail was abandoned because of the extra weight required for the two webs, and it was found, also, that the rail heads could not be made of harder granular iron for this form of section, as was the practice for the other, and this resulted in a reduced life of the rail.   As steel is the material for rails of the present day, the last objection does not apply, and the former objection loses its weight, as we are now called upon to provide a rail weighing from 80 to 100 pounds per yard, or about double 50, the weight of the bridge rails originally used.   The bridge rail is much more stable than the T-rail, giving a broader base, hence taxing the spikes far less, and the bearing upon ties can be made as wide as desired.   I have seen ties in a bridge floor spaced 1 foot between centers, so badly cut into by the rail, which was of a light pattern, that it was necessary to insert sole plates between the rail and the tie.   We have doubled the weight upon the wheels as compared with former practice, but we have not increased the width of base of our T-rails an equal amount.   Lastly, the bridge rail offers advantages in the splices not possessed by the T-rail, and would seem to solve the problem of an effective splice.   This alone may be considered a sufficient gain to justify the change.

Sketch herewith (Plate LXVIII) shows an 85-pound bridge rail with two kinds of splices.   For No. 1 no bolts are needed, or, if used, would have only a nominal duty to perform.   No difficulty would be found in making the splice sufficiently strong for the purpose.   The rail section shown has fully as much strength, to bridge the space between ties, as any T form of rail of same weight in use.   The reason for this is that the extra metal in the two webs is compensated for by the head, which is shallow and wide, and the center of gravity of which is further from the neutral axis than in the case of a T-rail.   As regards switches and frogs, there would be no difficulty in adapting the present forms of these devices to the new section.   It must be said, however, that the rolling of this section would be somewhat more expensive than the rolling of the T-rail, but this additional cost would be small, and is more than made up by the advantages secured.

ONWARD BATES, M. Am. Soc. C. E.—The author of this paper has asked me to discuss it; a hard thing for me to do, because to my mind it should go without saying that wheels should be cylindrical and rails flat topped.   If the paper advanced the converse of this proposition I think I could write a vigorous reply to it.

If there was no question of wear, I should favor conical wheels and round topped rails, for then the wheels would traverse a single element of the cylindrical rail top, and we might expect the circumferences of wheels to conform to the lengths of rails on curves.   But wheels and rails do wear, and experience indicates that wheels in use soon lose their conical shape with the advantages claimed for it.   With

conical wheels, the rails should be flat topped and inclined, so that on straight track the wheels should rest evenly across the whole portion of the rail top that is flat, and this inclination should be varied on curved track to fit the position which will be taken by the conical wheels. If it should be said that this latter requirement is more theoretical than practical, I would reply that the same criticism applies to the coning of wheels. With cylindrical wheels the rails should be flat topped and vertical.

Assuming, for sake of argument, that wheels and rails are incompressible, the area of contact between a conical or cylindrical wheel and a round topped rail is a point which geometry teaches us has no dimensions, and with the same wheel on a flat topped rail the area of contact is a line, with the one dimension of length. Consequently, according to Euclid, in the one case the wheel has nothing to stand on, while the other is a good line. With the compression that actually occurs there is a visible area of contact having dimensions of length and breadth, and which in Mr. Whittemore's experiments was of an oval shape. To obtain such contact displacement of metal must occur. This displacement is greater with the round topped rail, where the metal flows in every direction from a central point, than with the flat topped rail, where the flow is each way from a line. The total area of contact is small for the load sustained, and if the pressure varies over this area in proportion to the displacement, which I assume to be the case, the metal, where the displacement is greatest, must be strained far beyond its elastic limit, and the round topped rail, with its greater displacement, suffers more than the flat topped one. Immediate failure does not occur because the overstrained surface of the wheel or rail is supported by the mass of metal behind it, through which the pressure is diffused. Every loaded wheel traversing a rail strains the top surface of the rail beyond its elastic limit, causing surface wear. Another, and probably more serious result of this overstress, is deterioration of the metal in the direction of greatest pressure, as shown by the splitting of tires and of rail heads. Force acts in the direction of least resistance, and a tire or rail will inevitably suffer greater damage when the pressure is on a line or a narrow strip, than when distributed over a flat surface. One of my articles of engineering faith is that failure begins when the elastic limit of the metal is exceeded, and I cannot hold that faith and advocate a round topped rail. For those who believe differently I suggest a simple experiment. Take two strips of metal, one with a cross-section corresponding with the top ¼ of an inch of a round topped rail, and the other with the same portion of a flat topped rail; flatten them out by passing a roller over them in the direction of their length, and note the sults.

The question of the proper form for rails other than their top bearing surface is not here under discussion, and I have confined my remarks to

the relation of a wheel to this top surface. I believe that conical wheels and round topped rails are errors, which illustrate how long a fallacy may exist, and that it has existed so long confirms me in the belief that we shall yet see great and radical changes in our system of permanent way.

GEORGE S. MORISON, M. Am. Soc. C. E.—The general substance of the argument contained in Mr. Whittemore's paper is, that the weights now put on the wheels of railroad rolling stock are so great that the elastic limit of the rails and of the wheels is exceeded at the point of contact, and that to reduce the wear the area of contact must be so increased that the pressure shall be brought safely within the elastic limit.

This area of contact can be increased in two ways; first, by increasing the diameter of the wheel; and, second, by increasing the length of the line of contact. As wheels are necessarily round, comparatively little increase of contact is obtained by increasing the diameter of the wheel.   The surface contact, however, will increase directly as the length of line contact. Mr. Whittemore, therefore, proposes to use a cylindrical wheel, rolling on a flat topped rail, thereby securing a maximum length of line contact, obtaining exactly the conditions which are always sought for in rollers carrying extreme weights, or in machine finished work.

With perfect railroads, operated with the perfection of machine work, there would be no doubt of the correctness of Mr. Whittemore's proposition.   Unfortunately no such railroads exist.   The perfect railroad would be of uniform gauge, and without curves.   On such a road Mr. Whittemore's cylindrical wheels would roll on his flat topped rails with a rate of wear which would probably hardly be appreciated. All friction and wear would be reduced to rolling friction and rolling wear, and the conditions would exist under which rolling wear would be reduced to a minimum.   As soon, however, as we depart from this class of road new elements come in.   On curves we could retain the flat topped rail, but it would become necessary to change the two wheels to the sections of one true cone, as is done in the wheels of turn-tables, while perfection could only be obtained by means of other impossible requirements.

The question before us is entirely a practical one.   What we have to consider is how to obtain the maximum commercial value of the metal in rails and wheels.   The case is not analogous to the strains in bridge work, where, by keeping the strains safely within the elastic limit, deterioration is practically avoided.   It is admitted that rails and wheels must wear out.   The question is, what is the principal source of wear, and in what shape the minimum amount of metal will endure the maximum of wear.

Leaving out the questions of the special strains produced by the pull of locomotive driving wheels, the wear of rails and wheels is due to two

causes; the rolling pressure which Mr. Whittemore considers so import-
ant, and the grinding action caused by the wheels slipping on the rail.
If the rolling wear is the principal one, Mr. Whittemore's ideas should
be accepted in the design of rails; if, however, the grinding action is
the principal one, the form of rail should be sought in which this grind-
ing would be a minimum.

As to the rolling wear, there are strong reasons for questioning
whether elastic limit has as important an application in this respect as is
commonly supposed. Every one who has tested the strength of metals
knows how important the element of time is in all such tests. It takes
time for metal, even under extreme strains, to develop the stretch or com-
pression corresponding to those strains. In the case of a train running
at high speed on a railroad track, this element of time is so much curtailed
that the calculated compression in the rail head and in the wheel is un-
doubtedly very much reduced. The extreme strain does not exist long
enough to bring about that distortion of material which has a permanent
injurious effect, while the contact area is undoubtedly much less than
calculations or experiments on wheels at rest would indicate. The
action of thin ice under quickly moving weights has often been applied
to structural conditions to which it bears little or no analogy; it does,
however, bear a close analogy to the case before us. Thin ice will bear
a heavy weight moving rapidly, simply for the reason that the ice can
break only by the movement of the water under it, and there is no time
for such movement. With an extreme rolling load on a rail or wheel,
the metal cannot be extremely distorted, simply because there is no time
for that movement to take place. Besides this element of time, the con-
dition of shape has perhaps not been investigated as thoroughly as it
should be, and it must also be remembered that the elastic limit can be
varied very much by the process of manufacture, and that the direction
on which it is called to resist weight in a rail is entirely unlike the
direction on which tests are usually made.

On the other hand, all experience indicates that the wear of rails is
due principally to the grinding action caused by a slip. A familiar
illustration of this is the wear of rails on curves. If the track is laid
with an elevation too great for the speed at which trains are commonly
run, the outer rail is always found to wear out first, the wear being most
rapid on the side where the slip of the flange produces the maximum
grinding action; if, however, the curve has too little elevation the inside
rail will always wear out first, the wear being approximately a flat wear
on top of the rail, the rail usually assuming a shape which corresponds
more nearly to Mr. Whittemore's flat topped rail than is to be found in
any other portion of a track, and the wear being a maximum under these
conditions. The explanation of this unequal wear is very simple. With
too much elevation more weight is carried on the inside than on the out-
side wheel, and the latter slips. With too little elevation more weight is

carried on the outside than on the inside wheel, and the inside wheel slips; in either case, the wheel which has the greater weight on it rolls, and the one with the lesser weight slips.

The statistics collected by Mr. Wellington as to the wear of wheels, and contained in the Preliminary Report of the Committee, of which he and I are members, are principally valuable as showing how large a part the grinding action of the slipping wheel has to do with the wear of wheels and rails.

The conclusion which I individually draw from my own observations and from statistics, as far as I have examined them, is that the point to be studied is to produce a form of wheel and a form of rail head in which the slip shall be reduced to a minimum, believing that if we can once avoid the grinding effect of a slip we can stand the rolling wear of loads. In fact, I believe that the extreme loads now put on some of our car and locomotive wheels are objectionable, not from the wear they produce on the rail head, but from the effect on the lower portions of the track, the bearings on the ties, the spikes, the ties themselves, and the road-bed; on these their effect is so severe that I am strongly inclined to believe that a system of chair-laid track similar to that used in England may yet be adopted here.

To produce the minimum amount of slip, and, therefore, the minimum amount of grind, the line of contact between the rail and the wheel should be kept as nearly parallel as possible to the center line of the axle, and it should be no longer than is consistent with a reasonable approach to this condition. The former requirement is virtually the same as Mr. Whittemore's, but is reached from an entirely different line of reasoning. In practice, however, it must be somewhat modified, owing to the fact that wheels and tires will necessarily wear hollow so long as the width is greater than the width of the bearing, and safety makes this extra width absolutely necessary on every curved railroad. This brings us to precisely the conclusion given us in the Preliminary Report of the Committee, namely, that the head of the rail should be made with a large radius, but not absolutely flat—in other words, of a shape which will not produce exceptionally irregular results when the wheels become worn somewhat hollow; and, secondly, that the contact between the flange and wheel should be kept at as near the top of the rail as possible, which simply means that the upper corner of the rail should be given a minimum radius.

Of the three rails illustrated on the circular of April 20th, the best conditions seem to be made by Fig. 1, Michigan Central standard, the criticism which I am inclined to make of this rail being that the head is perhaps a little wider than is wise, and that a head $2\frac{1}{4}$ to $2\frac{3}{8}$ inches wide would probably give at least equally good results. The objection to so narrow a head is, of course, the inadequate support it gives for the fish plate.

Mr. WHITTEMORE.—Mr. Morison's statement of stresses on rails in a curved track must be received as correct. With the outside rail elevated to suit the fast moving passenger trains, the preponderance of loads carried by the slower moving freight trains operates to crush the inside rail and cause slipping and consequent abrasion of the outside one. Both rolling resistance and friction of sliding and its abrasive effect are reduced by having the areas in contact such as to keep the pressure within the limit of elasticity of both wheels and rails, and it must be admitted that these resistances, when the pressures do not exceed the elastic limit, are nearly in proportion to pressures and not to areas of contact. It must also be admitted that to reduce abrasion, the wheel should have a tread of one radius, and not a varying radii, as the curved-topped rail hastens to make it.

Mr. Morison expresses the belief that our heavy loads on car and engine wheels are not objectionable from the wear they produce on the rail head, but are so in their action on the lower portion of the track. The author's effort has been to show that we do not destroy our rails so much through abrasion as by crushing them. Exceptional cases can be cited where great abrasion occurs, such as on steep gradients, where brakes are used to check velocity and sand is employed for additional driver adhesion, where switch engines are used in and near yards where sliding of wheels is common and sand abundantly used, and also along sharp curves elsewhere in the main line, as is abundantly shown by several of the diagrams furnished by our President. ,

Under our heavy loads the injury to the track by reason of the rail cutting into the tie is severe, and the remedy suggested by Mr. Morison should be earnestly considered.

Many of our railways have nearly 3 000 ties to the mile, while in England and on the continent only about 2 000 are used, but the latter are longer and wider than ours.

There is no doubt in my mind that through the use of sole plates of proper size and with longer and broader ties, a less number of ties will be required than we now generally use on our properly ballasted lines.

ROBERT W. HUNT, M. Am. Soc. C. E.—I have studied Past President Whittemore's able paper on "Cylindrical Wheels and Flat Topped Rails" with attention and much pleasure. In discussing it I approach the part in relation to wheels with less confidence than that pertaining to rails. We know that the augmented traffic has increased the wheel loads to an enormous extent. I called attention to this in my paper on "Steel Rails and Specifications for their Manufacture," presented before the American Institute of Mining Engineers, October, 1888, by giving the determinations of one fellow member, O. Chanute, M. Am. Soc. C. E., in 1881. To these Mr. Whittemore adds additional data.

It does not require any further argument to demonstrate that the rail of to-day must be of an increased section. It only remains to de-

termine the best form to give it. I am so thoroughly committed to a section having increased width rather than depth of head, and have so fully and repeatedly presented my arguments in its favor, that I will not here repeat them. I know you can obtain a better piece of steel in that form than when the head is deeper.

That increased wheel loads should require additional surface for contact, and hence support, seems to be self-evident. It has been proved that rails which originally had top curves of small radii have in service been worn to much larger ones. And it is also true that the earlier rails presented much greater surface in contact, in proportion to their loads, than later ones. And they also gave better results. It would, therefore, impress me as being true wisdom to go back toward successful practice, rather than continue in the direction we know has not, from some cause, given so satisfactory results.

Mr. Whittemore is radical in his propositions, and, no doubt, so tended. Of course, the rails of any railway system will be subjected to the wear from the rolling stock of the whole country. Hence until all roads adopt an universal standard for their wheels, we will not have constant conditions. But that is not a logical reason why the best forms should not be accepted, and used by somebody. There must be a beginning to all things.

In the sections which I have designed, and which I had the honor to present to the American Institute of Mining Engineers at their New York meeting in February, 1889, I adhered to a top radius of 12 inches, and did so more in a spirit of conservatism than because I believed it to be absolutely right. But less than that I cannot approve.

It is a little more convenient, on account of roll dressing, for the rail makers to have some curve to the top of the rails ; but this is not a necessity. Flat tops can be rolled as well as flat bases. In fact, during my experience in rail inspection I have found one mill from which it has been a constant difficulty to obtain rails which were not rolled flat when the section had a head at all wide. In short, so far as the manufacture is concerned, and if flat topped rails are right, the makers can produce them without serious inconvenience.

I have been asked if it is absolutely necessary to have a middle "parting" to the rolls. In other words, whether this could not be on one corner of the rail head. If I remember correctly, A. J. Gustin—inventor of the rail cambering machine bearing his name—when in charge of the St. Albans Rolling Mill, St. Albans, Vt., so turned all of his rail rolls, and claimed much merit for the system. I have never known of any other mill having this practice, but it can be done. Still, as I have already stated, this would not be necessary to roll flat topped rails. We had them in service years before steel rails were invented, and of course produced on the slow running, old-fashioned, "two-high" mills.

We owe Mr. Whittemore much for his investigations and this con-

tribution to the literature on "Steel Rails." It is from such sources we must seek true information. Let the civil engineer design his sections, based on the safe foundation of experience ; at the same time let him be willing to give due consideration to the criticisms and advice of the metallurgical engineer. The two acting in harmony will the sooner secure that which we all desire—the best.

OLIN H. LANDRETH, M. Am. Soc. C. E.—The importance of the evils which Mr. Whittemore proposes to remedy, viz., undue wear of rails and wheels and the failure of rail heads before they have given more than a fraction of what may be considered a reasonable tonnage service, has never been more clearly set forth than in the paper of Mr. Whittemore and permits of no contradiction.

As to whether Mr. Whittemore's proposed form of rail top and wheel tread constitutes the most effective and the most feasible remedy attainable for these two distinct evils, is a question for discussion.

Individually I am inclined to the opinion that flat top rails (flat when laid) would constitute an improvement in reducing rail wear, but I do not recommend an entirely flat top rail, because I believe that would be overdoing the proper remedy, and would not insure so low a rate of wear as a rail top having a radius of curvature greater than 14 inches, but not entirely flat.

My reasons are based on the following considerations, which are confined to top rail wear alone, and exclude side rail wear as in no way effecting the special question of top curvature.

When a rail has worn to a permanent form of curvature it has reached a condition of nearest possible approach to a uniform distribution of wheel load, and hence the lowest maximum wheel pressure across the rail top, and therefore has attained its minimum rate of wear. Could a rail have been given at first a curvature which should remain permanent in radius, it would therefore insure a minimum rate of wear throughout the life of the rail. Such a curve should be sought, and when determined, should be adopted in the manufacture of the rail. A top curve, which should remain permanent throughout the life of the rail, would doubtless differ from the permanent curve assumed by a rail that had worn to its permanent form from a curvature originally sharper or flatter, since the form of the original curve would affect the form of the tread wear of the wheels rolling on it, and this form of tread wear would in turn effect and determine the form of the ultimate curve assumed by the rail top.

Car wheels rolling over rails ranging in original curvature from 6 to 10 inches top radius ultimately wear all rails on which they run to an average top radius of about 14 inches on tangents and about 10 inches on curves. Were all rails of a new system laid originally flat, and all car wheels running over them originally cylindrical, it appears impossi-

ble to escape the conclusion that the rails would ultimately wear to a curved form, and that the permanent curve assumed would be flatter in curvature than if the rails had been laid with the usual 6 to 10-inch radius. The grounds for these conclusions are :

First.—It would be impossible to lay rails, or mount wheels, or maintain either, so truly as to insure a uniform bearing of the cylindrical wheel on the flat top rail. Owing to this, there would result an augmented wheel pressure and an augmented wear toward either one edge of the rail or the other, or both edges, successively, according to the condition and rigidity of the rail-fastenings, and a curved form of the rail top would result.

Second.—Even were this impossible uniformity of wheel pressure across the rail attainable, the different portions of the rail top are not equally strong against wear under heavy compression; the portions near the edges having less metal outside would be deformed under lighter pressures than the central portions, and the same effect, viz., a curved rail top, would be the result.

Third.—The curve thus produced would gradually become sharper, until a permanent form should be reached, which, however, would be flatter than if t he rail had been laid with the usual curvature of 6 to 10 inches radius, since the wheels starting originally with straight cylindrical treads, and being worn more by the outer portions of the rail top than by the inner, would remain straight across the tread, or if worn curved, would assume a flatter curve than if the rails had been laid with the usual sharp top curve; hence the permanent curve assumed by the rail—which is dependent on the curve of the wheel tread—would also be flatter than the permanent curve which the rail would have assumed had it been laid with the usual sharp curve, *i. e.*, the permanent curve would be flatter than 14 inches on tangents or 10 inches on curves. The exact value of this radius it is impossible to determine in the absence of experience with flat top rails, but it is hardly probable that it would be less than 20 inches under ordinary conditions of track or 30 inches where unusual precision in track laying or great rigidity of rail fastenings should exist.

If now a rail of 6 to 10 inches original radius wears flatter and assumes a permanent curve of about 14 inches radius, and a flat top rail wears sharper and assumes a permanent curve of from 20 to 30 inches, say 25 inches radius, it follows that the curve sought, viz., one that would wear neither flatter nor sharper, should have an original curve of radius between 14 and 25 inches; the precise value of this "radius of no variation," while falling between the above limits, could be precisely determined only by experience. I am strongly inclined to the opinion that rails laid with such a top curve, *i. e.*, one of about 20 inches radius, would result in a lower rate of top rail wear than either our present forms or Mr. Whittemore's proposed flat top rails, and would give equally low rates of side rail wear.

But I do not believe that rail wear proper is the only or the most important evil that reduces the life of our rails. Mr. Sandberg objects to the flat top rail from the "producers' point of view," for the following two reasons:

1. The heads of flat top rails would be more porous than curved top, because the flat top necessitates less pressure or work in the last roll groove, and hence less close grain than the curved top.

2. The heads of flat top rails would not deliver so well from the rolls and more "wasters" would be the result.

The first objection appears to me to touch the true root of the evil of undue rail wear, viz., a lack of density and hardness in the heads, but should not be directed against flat top rails alone and made a ground for their rejection, for the difference of density of rail head due alone to the form of curve of rail top must be quite insignificant, since it is measured by the versed sine of one-half of the top curve, which in the flat top rail would be zero, and in Mr. Sandberg's rail of 6 inches radius $\frac{1}{12}$ of an inch. In either form the density is mainly given—as in the perfectly flat base of the rail—by the pressure or work of the rolls acting upon the semi-fluid metal, and forcing it against the vertical surfaces of the rail grooves, which act simply as molds to shape the rail base and head.

As the rail metal at its passage through the last grooves is far from being perfectly fluid, the final pressure on the rail head and rail base is far from being equal to that produced by the rolls on the web and sides of the head. This remarkable fact, that the portion of the rail on which the heaviest and most severe service falls is the very portion on which the least pressure and work in the rolls is expended, points to the desirability of considering whether modifications or additions to our present mode of rolling rails may not be possible. As Mr. Whittemore remarks, "A way is always found to do what must be done," and when engineers of maintenance of way shall become satisfied—as I believe they must—that their rails, in order to render a reasonable tonnage service, must not only be so improved in top curvature as to increase the durability of the rail surface, but must be made proof against crushing and disintegration under our heavy wheel loads by acquiring physical hardness and density without sacrificing toughness, then the mechanical engineer and rolling mill manager may be depended on to meet the demand by improvements in manufacture; possibly not without increased cost of production; but the margin of possible improvement between the tonnage service that our rails actually average, and that which good rails under similar conditions are known to give, is so wide, that a considerably increased cost of production would be warranted in securing the higher service.

The second objection, concerning the difficulty of delivering flat top rails from the rolls, is doubtless a valid one, but one which would be

obviated by giving the rail any appreciable curvature which should release the horizontal grip of the rolls on any one portion of the rail head as soon as that portion should have passed the point of contact with the rolls, or as Mr. Sandberg says, "as long as the rail is not flat;" hence the 20-inch radius herein proposed would not be subject to this objection.

J. B. JOHNSON, M. Am. Soc. C. E.—Mr. Whittemore bases his tables of allowable wheel loads for given radii and unit stresses on formulas of Professor Grashof, which, as he gives them, are erroneous. These formulas are given as general, and suitable to any unit of measure, as the inch, the foot, the centimeter, etc. If this be so, then we should obtain the same result, whatever unit be used. Thus, if we use the foot unit, for $E K$ and R, then the value of P found should be the same as when the inch unit is used, since this load is independent of any dimension. Taking the foot as the unit of measure, we obtain twelve times as large values from the first formula (cylinder on cylinder), and $\sqrt{12}$ times as large values from the second formula (cylinder on a plane). This proves the formulas to be defective somewhere.

Since the derivation of these formulas is simple, we may as well derive them at once and find the error.

RELATION BETWEEN TOTAL LOAD AND MAXIMUM STRESS, WHEN ONE CYLINDER RESTS ON ANOTHER AT RIGHT ANGLES TO IT.

It will be assumed that the maximum stress is within the elastic limit of the material, and hence that the stress varies as the distortion.

When one cylinder rests across another, the area of contact is an ellipse. The maximum stress is at the center and is proportional to the distortion at this point. The total distortion of one of the cylinders, if referred to a plane base, would be the segment of an ellipsoid, but so small a segment that it well might be considered the segment of a paraboloid. Similarly, since stresses are proportional to distortions, if the stresses over this area of contact be plotted from a plane of reference, the surface formed by their upper extremities may be taken as the segment of a paraboloid. Now, the average length of ordinate to a paraboloid is $\frac{1}{2}$ the length of the maximum ordinate, or the volume of a segment of a paraboloid is $\frac{1}{2}$ the inclosing cylinder. This volume would represent P, the total load, since any ordinate represents the intensity of the stress at that point.

We have, therefore,

$$P = \tfrac{1}{2} K A \dotfill (1)$$

Where $K =$ maximum intensity of stress, and $A =$ area of surface of contact.

It remains to find the area of contact in terms of the two radii, the moduli of elasticity and the maximum stress.
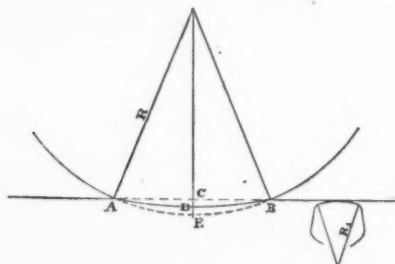
In Figure, let $A\,C\,B$ represent the original surface of the rail, and $A\,E\,B$ the original surface of the wheel. These surfaces are now both coincident in $A\,D\,B$.

The length of $A\,C$ is, by geometry, equal to

$$\sqrt{(2\,R - \overline{CE})\,\overline{CE}} = \sqrt{2\,R\,\overline{CE} - \overline{CE}^2}.$$

Since $\overline{CE}$ is very small as compared to $2\,R$, we may neglect its square, and if we put $A\,C = d$, and $\overline{C\,E} = e$, we would have

$$A\,C = d = \sqrt{2\,R\,e} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

Now $e = D\,E + C\,D$, and these distances are the distortions of wheel and rail respectively under the common intensity of stress K.

Now the formula for the modulus of elasticity is

$$E = \frac{K\,h}{a}, \text{ or } a = \frac{K\,h}{E},$$

where E is the modulus of elasticity;

K " intensity of stress per unit of area;

h " length of fiber under stress K;

a " distortion of fiber whose length is h.

But in our problem $D\,E = a$ for wheel, and $C\,D = a_1$ for rail, hence we may write:

$$D\,E = \frac{K\,h}{E}, \text{ and } C\,D = \frac{K\,h_1}{E_1},$$

and $D\,E + C\,D = C\,E = e = K\left(\dfrac{h}{E} + \dfrac{h_1}{E_1}\right) \dots\dots\dots\dots\dots\dots (3)$

Substituting this value of e in formula (2) we have:

$$d = \sqrt{2\,R\,K\left(\frac{h}{E} + \frac{h_1}{E_1}\right)} \dots\dots\dots\dots\dots (4)$$

This is the semi-axis parallel to rail of the elliptical surface of contact.

The semi-axis of the surface of contact across the rail would be

$$d_1 = \sqrt{2 R_1 K \left(\frac{h}{E} + \frac{h_1}{E_1}\right)}$$

where the subscripts refer to the constants of the rail instead of the wheel.

Now the area of the ellipse of contact is

$$A = \pi \, dd_1 = 2 \pi K \left(\frac{h}{E} + \frac{h_1}{E_1}\right) \sqrt{RR_1} \dots\dots\dots\dots \quad (5)$$

and from equation (1) we now have $P = \pi K^2 \left(\dfrac{h}{E} + \dfrac{h_1}{E_1}\right) \sqrt{RR_1}$ (6)

This is the first equation given in the paper under discussion, with the exception that where h and h_1 appear in this equation, he has unity. But h and h_1 represent the lengths of the compressed elements of rail and wheel, and when they are called unity, it means that these elements are one unit in length. If the unit chosen is the inch, then these filaments are assumed to be 1 inch long, but if the foot is the unit chosen, then they are assumed to be 1 foot long. With our formula (6) the result is the same, whatever unit is chosen.

The proper evaluation of h and h_1 in this formula is most uncertain from purely *a priori* grounds. They should be evaluated by experiment. There is no doubt but that the stress is rapidly spread over an area much larger than the area of contact, through the shearing stresses that are brought into action, and that consequently the maximum stress K, rapidly diminishes in value as we proceed from the surface of contact. The equation is derived, however, on the assumption that the vertical elements of the wheel and rail in contact are separate and distinct from each other, that they all have a definite length, h for the wheel, and h_1 for the rail, and that these lengths rest at their other extremities on absolutely rigid surfaces. All these assumptions are so far from the truth that it is really impossible to apply the formula to any particular case, except by the aid of experiment.

RELATION BETWEEN TOTAL LOAD AND MAXIMUM STRESS, WHEN A CYLINDER RESTS ON A PLANE SURFACE.

Referring again to the figure above, and understanding that the lower form is a plane, and taking a cylinder of one unit's length along its axis, and reasoning as before, we may say that if the stresses be plotted from a plane surface, the volume thus formed will be the segment of a cylinder, one unit long, the maximum ordinate being K, the maximum stress. Since this segment is very small, it may be taken as the segment of a parabolic cylinder, in which case its volume, which represents the total

stress, P would be $\frac{2}{3}$ the inclosing parallelopipedon, or $P = \frac{2}{3} K A$, where K is maximum stress, and A is the area of the surface of contact.

Referring again to the figure, we have $A = $ width $A B = 2 \overline{CB} = 2 d$, since the length of cylinder is unity.

As before, we may say, $d = \sqrt{2 Re}$, where $e = \frac{h}{E} + \frac{h_1}{E_1}$

$$\therefore \ P = \frac{4}{3} K \sqrt{2 R \left(\frac{h}{E} + \frac{h_1}{E_1} \right)} = \sqrt{\frac{32}{9} K^2 R \left(\frac{h}{E} + \frac{h_1}{E_1} \right)} \ \dots (7)$$

This is the same as Mr. Whittemore's second equation, except that we have h and h_1, instead of unity. This equation was derived by the writer as an improvement on one quoted by Mr. Charles Macdonald, M. Am. Soc. C. E., from the German, in a discussion in *Transactions* Am. Soc. C. E., 1874, p. 140; and it was published in the *Journal of the Association of Engineering Societies*, Vol. IV, p. 110, having been embodied in a paper before the St. Louis Engineers' Club, November 19th, 1884. In that discussion, however, the object sought was the bearing power of bridge rollers, and the lengths of the elementary columns (h and $_1$) in compression were both assumed to be equal to the radius of the roller.

Since friction bridge rollers are from 2 to 3 inches in diameter, the error in this assumption was small, the formula then being,

$$P = \sqrt{\frac{32}{9} K^2 R^2 \left(\frac{1}{E} + \frac{1}{E} \right)} \ \dots\dots\dots\dots\dots\dots\dots (8)$$

The Above Formulas Practically Worthless.

It is now proposed to show that all the above formulas are absolutely worthless for solving practical problems. Since Mr. Whittemore's paper appeared the writer set about making some laboratory experiments for the purpose of amassing data on which to rest a valid argument. A section of a 33-inch chilled wheel, one of a 44-inch steel-rimmed driver, and several short sections of rail were prepared for experimental tests of areas of contact in a 100 000 pound testing machine. Contacts were made with both wheels with loads varying from 5 000 to 60 000 pounds.

It was found that the area of contact varies directly with the load, or, in other words, the average intensity of stress $\left(\frac{\text{load}}{\text{area}} \right)$ is a constant for all loads.

The experiments are not yet complete (October, 1889), but it is believed this is very nearly the law. This is directly contrary to the deductions made from Fig. 1.

The law seems to be for 22-inch radius steel tire, on 14-inch radius steel rail,

$$A = 0.000012 \, P \tag{9}$$

where A is area of contact in square inches, and P is the load on wheel in pounds. What the maximum stress is cannot now be stated, but if the mean stress is about a constant for all loads, it is probable that the maximum stress is nearly a constant also.

Furthermore this maximum stress must be nearly twice the mean stress, since the maximum distortion must, of necessity (a geometrical necessity), be twice the mean distortion.

We may therefore say that the maximum stress is nearly

$$K = \frac{2P}{A} \qquad (10)$$

and from (9) we obtain for a 44-inch steel driver on a 14-inch radius steel rail,

$$K = \frac{2P}{A} = \frac{2P}{0.000012\,P} = 167\,000$$

pounds per square inch.

This astonishing result seems at first incredible, but it cannot, in the writer's opinion, be successfully disputed. All the data of these experiments will, at an early day, be laid before the Society. A few of the more important conclusions only are given here. In the meantime it would be well for other investigators to make similar experiments. I have found that a little wet chalk or whiting rubbed on the surface to be placed in contact, takes the impression as well as anything, and is quite satisfactory. The impression can then be copied off on tracing paper.

This result leads at once to the study of the elastic limit in compression. Here is where we have all been blundering. There is no such thing as an unconditioned elastic limit in compression as there is in tension.

The elastic limit is the point where the material begins to permanently distort or flow, or where the particles begin to rearrange themselves in new positions.

Now, for compressive stresses, we have various conditions limiting the flow of the particles. For instance, a cylindrical column in compression is in a condition of free flow. There is nothing to hinder the lateral spreading action of the column as it shortens up. If we place a square-ended die on a flat surface and load it until it begins to indent that surface the material below the end of the die must flow laterally around the corners of the die to get out of the way. But this lateral flow is restricted by the surrounding metal. Here we have a restricted flow, and a much higher pressure is required before it will occur.

But when a sphere or cylinder is placed on a plane, or one cylinder on another cylinder, and loaded, the maximum stress and the greatest tendency to flow is at the center of the area of contact, and here the flow must begin. But this metal cannot find as near escape as in the case of

the square-ended die, for the pressure diminishes gradually and the flow must be through a longer distance before it can really escape. Here, therefore, is a case of still greater restriction of flow and still higher elastic limit.

I estimate that a grade of steel having an elastic limit in compression when tested as a column, with free flow of some 40 000 to 45 000 pounds per square inch, has a limit of about 100 000 pounds under a square-ended die, and of some 160 000 to 200 000 pounds under curved surfaces of as much as 20 inches radius.

Observations on this subject are also in progress at the Washington University Laboratory, St. Louis, and it is hoped they will also be made elsewhere.

The conclusion which I am coming to is, therefore, that the maximum stress in and also the elastic limit of steel rails under wheel loads is dependent on the radii of the wheel and the rail, and that the maximum stress is practically independent of the total load on the wheel. Also that the elastic limit is in the vicinity of 200 000 pounds per square inch for the ordinary locomotive drivers on the ordinary steel rails.

These conclusions are so contrary to the commonly received opinions on this subject that the writer hopes that by the time his forthcoming paper on this subject appears others will have made similar experiments, and can thus either fortify his conclusions or prove them erroneous.

EQUIVALENT SURFACE OF CONTACT.

When a wheel tread becomes worn or grooved, and the rail head becomes flattened somewhat, so that the surface of contact is extended laterally across the rail from 1 to 2 inches, the effect on the intensity of the stress is the same as though we had a flat wheel on a flat rail.

It is sometimes said that if a flat topped rail is the surface of least wear the rail would constantly approximate to this form. This is not true. If the rail is originally curved, and the wheel tread flat or conical, the final section of both will be a mean between the two original surfaces. And this is exactly what happens. The tread becomes grooved, and the rail becomes flattened, both approximating to a mean between the original curvature of the rail head and the flat tread. When they have both come to the same curvature, the effect is exactly the same as a flat tread on a flat rail.

If, now, both wheel tread and rail top should be made flat in the start, I see no reason why they should not remain so, except from the rounding off of the corners somewhat as a result of the grooved drivers shifting slightly in a lateral direction. If, when the rail is first laid, it cants slightly, it will soon adjust itself by cutting into the tie more on one side than on the other, from the increased pressure on the high side.

If a flat head cannot be rolled, then let the head be as flat as can be rolled, for certainly a wider surface of contact is of the first importance.

Mr. WHITTEMORE.—While I cannot know in what order the several criticisms will appear in print, I desire to say that through my absence from the country and also in the knowledge that Professor Johnson was investigating the subject experimentally, and possessing the desire that some of his results might appear in this discussion, the publication of the paper and discussion has been delayed, until this late day, and not through any fault of the Secretary.

If we admit that the able analysis of Professor Johnson is correct, it will then be seen that our excessive loads do strain the metal much beyond the limit of elasticity as usually determined, even when considered as static loads, and undoubtedly their destructive effects are largely augmented when under motion and subject to violent impact.

Dr. Grashof's formula, I believe, has been considered about the safest to use, as he does not take into consideration that any support is derived from metal outside of the space of contact, but he does advise that the modulus of elasticity to be used in his formulas be ascertained from experiments under similar conditions of stress. It has been usual, however, to use it as ordinarily determined.*

It must be conceded that any generalization derived from the application of formulas to observed areas of contact as usually made, must be received with considerable allowance for error. The insertion of paper or pigment between bearing surfaces for the purpose of securing impression of areas of contact, must necessarily show greater areas than the absolute contact, as these materials are themselves compressible.

Perhaps the most accurate method by which the law governing contacts of spherical or cylindrical surfaces, with like or plain surfaces under varied pressure, can be best determined is in the way Newton's colored rings are observed, in which case we are compelled to use glass or other transparent substance for the experiment. That celebrated philosopher showed that by pressure the dark spot at and surrounding the center of contact of a lens on a plane increased as the pressure was increased, and it seems to me that by observing this increase under varied pressures up to near the limit of elasticity, the laws governing increased area with increased pressure may be pretty accurately determined, and that this, with experiments on metals strained to beyond their elastic limit, may afford sufficient testimony to establish the laws governing contacts of metals.

It is hoped that Professor Johnson will be able to pursue his experimental inquiry further and give the results of his labors to our society.

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* Dr. Grashof cannot be considered the first, however, in this field of inquiry, and those who wish to know something of what has been done before his work was issued, are referred to papers by Kopcke in Deutsche Bauzeitung, 1869; Kubler in Zeitschrift des Vereins Deutcher Ingenieure, 1874; Stevart in Revue Universelle, 1874; and by E. Winkler in Gittertrager, 1875.

Granting his premises, then it is seen what enormous stress is concentrated on a point, in the case he cites. We are taught that the Almighty never created but one perfect man, hence, how impossible it is for man to produce metal perfectly homogeneous; there will be faults in a steel rail, such as specks, cinders, voids by piping, and from other causes, even when the greatest care is taken in manufacture, and these may be near to this great concentrated stress, and it is here that the metal's apparent limit of elasticity would naturally approximate to what it would show when tested without adjacent support, and it is also here that failure may be first expected.

We have ample evidence to show that the best of metal in rails does flow during repeated applications of stress; hence it is that I offer my plan to avoid, as far as practicable, these concentrations.

Since an abstract of my paper was published, it has received criticisms in our engineering journals. One of these critics has intimated that by test he has never been able to detect a permanent depression on a rail from an over-loaded wheel, or words to that effect.

To such as may be influenced by such reasoning I respectfully suggest this line of thought:

We will suppose that a line is laid with what all will concede a very poor quality of rails, such as show a wear or depression on tangent rails of say one-half inch to a tonnage of ten millions only. This will give five million tons to each rail. Now suppose the wheels passing over the rail to be loaded to five tons, this would indicate that each loaded wheel as it passed would depress the metal one two-millionth of an inch. Have we any means by reflectors or otherwise for measuring such small increments?

While in the act of dictating the above the following communications are handed me, and with permission of the authors I insert them here as evidence pertinent to the subject, and in support of my position.

CHICAGO, ILL., October 11th, 1889.

D. J. WHITTEMORE, Esq.,
        Milwaukee, Wis.:

Dear Sir,—I am considerably interested, not as an expert, however, in the question of conical or coned wheels and the proper shape of rails on which they run. Sometime ago I went from Chicago to Albany with Mr. Edward W. Jackson, General Manager of the Mexican Central, in his private car. The wheels were cylindrical wheels, and the car rode very nicely, and I had quite a conversation with him in regard to wheels and rails. He is decidedly of your opinion, and I have asked him to send me some data with a blue print showing his idea of what wheels and rails should be. I have the letter and blue prints. Please find enclosed the print, which after examination and use kindly return to me.

Plate LXIX only shows wheels; he is in favor of rails to correspond.

        Yours truly,
                (Signed),   E. L. CORTHELL.
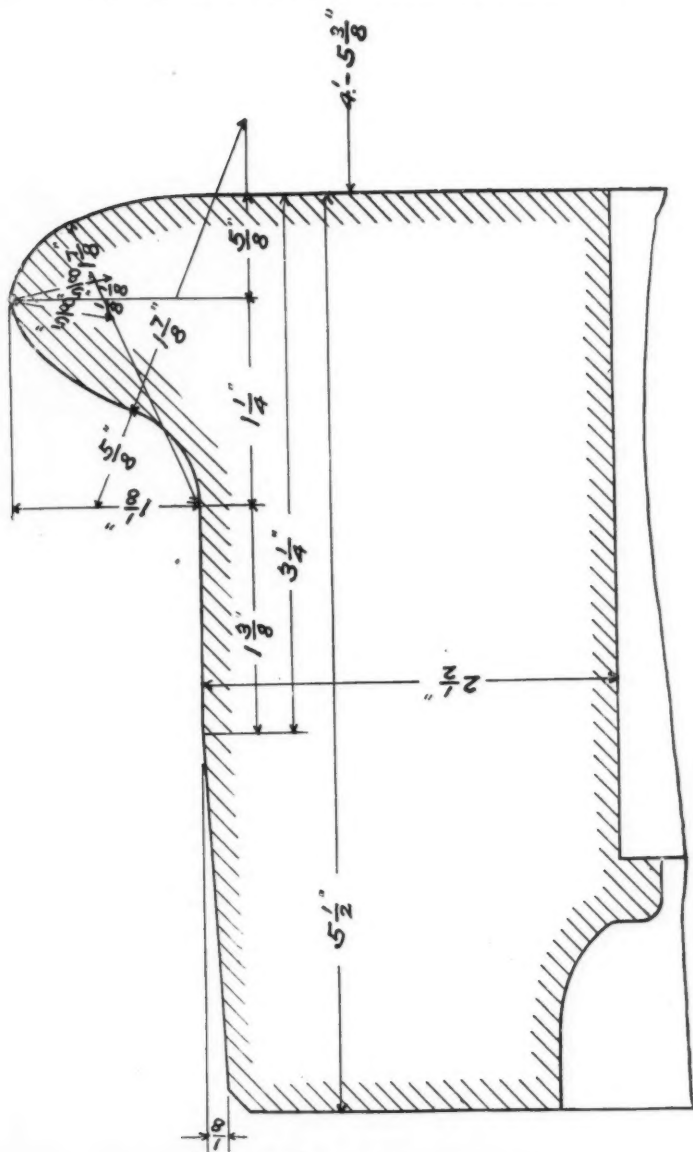
STANDARD TIRE FOR CAR WHEELS, MEXICAN CENTRAL RAILROAD.
Mexico, June 25th, 1883.—Scale: Full Size.

Approved by EDWARD W. JACKSON,
General Manager.

Plate LXIX.

MEXICO, September 27th, 1889.

Dear Mr. CORTHELL:

I have the pleasure to acknowledge receipt of your letter of the 5th inst.

I had not forgotten the question, but have been so extremely engaged since my return that I have omitted to attend to it.

I now send you blue print showing the tires as we turn them.

You will observe we have 1⅜ inches of flat cylindrical wheel, bevelled off to the outside edge of same, so that we have 2⅛ inches of cone and 1¾ cylindrical tread.

You had an opportunity of seeing how my car (which is a light one, only 51 feet long) and four-wheeled trucks rode behind fast trains on which you and I traveled.

I also mentioned to you that several years ago I had occasion to note this on an old car on the Mexican road.

I sent to the United States for paper wheels from the Allen Wheel Company, which were put under my car, and she whipped so terribly that I was obliged to set her out at the first station from Mexico.

I spoke with the Master Car Builder about it, and he explained the reason.

I then had the wheels turned down, and they have run admirably ever since.

When wheels are too much coned the least deviation from perfect track starts them rolling, and they keep it up frequently until another inequality produces a similar result.

                    (Signed)   EDWARD W. JACKSON,
                                        General Manager.

F. COLLINGWOOD, M. Am. Soc. C. E.—As others have had more recent experience than I on the general subject of rails, I shall confine my comments on the valuable paper by Mr. Whittemore to the single question of the state of the rail when under pressure.

It has been stated that ordinary compression tests do not apply in this case; and as a proof it is said that a beam of light reflected from the rail shows no change in the rail surface when the latter is pressed by a heavily loaded wheel.

One cannot examine the several sections of used-up rails illustrated in Mr. Whittemore's paper without being struck by the very strong indications of a splitting action having resulted from the applied load. Now we have a precisely parallel case in the use of hooks to chains and sheaves for hoisting heavy weights. The area of contact of the inside of the hook with the inside of the ring or wires is doubtless still more limited than in the case of the wheel and rail.

In the case of the hook we know there is a gradual deterioration of the metal from continued use, so that the hook becomes unsafe. It would seem as though each time it hoists a heavy load a certain line of the molecules are left in a state of strain, as if a wedge had been partially driven; and this action continued finally results in rupture. As an illustration I would mention a hook I saw break under about 7 tons oad, which had repeatedly hoisted 11 tons. This is so well recognized

now with cranes in constant use that it is customary to anneal all such parts at stated intervals, to restore them to their normal condition.

Now the surface of contact spoken of by Mr. Whittemore with an area of about 1 square inch is not, from the nature of the case, uniformly pressed; and we are not justified in assuming that some portion of it is not left in a state of strain. If it is, then it is only a question of time when disintegration in some form will make itself manifest. If such action does occur we ought to have exactly such sections resulting as those illustrated in the paper, and I see no reason for trying to dodge the conclusion.

Having gone thus far, we come to the question, is it practicable to devise a form which shall remove or lessen this danger? We here trench on the province of the rail-maker. The form suggested in the paper would certainly be practically free from the splitting action suggested; and there remain two questions to be answered concerning it: 1st. Can it be rolled? 2d. Will the metal in the head be in as good a state to withstand wear—that is, will it get its due share of work in the process of rolling?

It is quite possible that some radical change in practice at the mills might be required to give an affirmative answer to both these questions, but I would like to see it tried. We shall never get nearer to a perfect rail by doing nothing but theorize about it. Is it impossible to roll the wearing surface of a rail?

J. M. GOODWIN, M. Am. Soc. C. E.—I submit my opinion that, let the shape of the "corner" of the rail be what it may, persistent jamming and grinding of a wheel flange against the rail will have the effect of cutting away, and "sharpening," the flange so subjected to grinding; and that a rail corner having a distinctly "large" radius will, in time, put a "knife edge" on the flange, while the corner of less radius will wear more into the fillet of the flange. A rail having a "square" edge would, probably, wear the inside of the flange into a vertical plane. To the Master Car Builders, sitting in Convention at Chicago, in 1883, an English railroad man (invited to address them while the subject of "sharp flanges" was under discussion) put this question: "Did any one of you ever see two 'sharp' flanged wheels on one axle?" After "pausing for a reply," which he did not elicit, the gentleman proceeded to state that in several years of observation, in his capacity of superintendent of rolling stock, he had never seen two sharp flanges in association; and that when you see a sharp flange, you may be quite sure that the wheel, on which it is, has, or had, a mate of circumference greater than its own.

The fact is obvious, that if of two car wheels, fixed on one axle, one is "larger" than the other, the larger wheel will "drag" the smaller, and will operate to jam the leading flange of the smaller wheel against its rail; and we may reasonably conclude that a flange so jammed, and ground, against a rail, will, in due course, wear "sharp."

In case of mismatched wheels, the forcing of the smaller wheel to the rail is, presumably, persistent; reversing the direction of movement of the car merely reverses the direction of cut of the wearing surfaces, of flange and rail respectively.

In any case of "sharp flange," the circumstance that only one flange in a truck is affected is diagnostic of "big wheel." Where diagonally opposite wheels show undue flange-wear, one may expect to find the truck, in which they are, "out of square," or rigidly fixed at an angle with the draft line. Cases of absolute center rigidity of truck are not entirely unknown to the experienced car-repairer ; rigidity due to excessive side bearing, caused by uneven loading, or by over-loading of car, announcing itself through a harsh sound of grinding of flanges and skidding and twisting of wheel-treads on the rails, is to be detected by the practiced ear in almost any train of loaded cars. It is the cause of much flange grinding, and, of course, of much waste of locomotive power.

Considerations of convenience induce establishment of straight tracks at places at which cars are to receive cargo. This is a happy circumstance, inasmuch as it operates to produce squareness of the trucks with the car body, and track, pending the operation of loading; whence, if rigidity is produced by overloading, or side-loading, the truck is fixed straight with the car.

Load an eight-wheeled car, on a smart curve, to the right, for instance, and, by any means, fix the trucks, or either of them, so that prompt response thereof to flange pressure, tending to traverse the truck, is impracticable. Then at the first curve to the left encountered by the car the right hand leading wheel of the cramped truck will climb over the rail, except, indeed, the corner of the rail has a distinctly small radius; in which case the flange may not be able to get a "climbing hold." If the wheel cannot escape by climbing, fillet grinding results.

In view of the fact that while of eight wheels under a car seven run without developing sharp flange nor any tendency thereto, while the flange of one wheel of the eight wears "sharp" or is ground out in the fillet, we may reasonably conclude that the one flange has been, recurrently or constantly, subject to extraordinary wear, referable to some condition affecting it particularly. This conclusion is, of course, irreconcilable with any theory in which the shape of the corner of the rail appears as an active, positive, value.

I have only time, now, to say, further, that I advocate cylindrical wheels and flat top rails now, as always heretofore.

Mr. D. J. WHITTEMORE.—The author decidedly dissents from the conclusions of some who have participated in this discussion, in the plea that having track slovenly laid and rails poorly inspected, we must have a curved top to the rail to secure a bearing at or near

the center of the rail head ; also that the head, if made flat and subject to pressure of cylindrical wheels, will soon acquire a curved form between corner curves to any appreciable extent, through the lateral movement of the wheels of about one-quarter of an inch either way from their central or normal bearing on tangent rails. When the rails are laid as nearly true as is reasonably practicable, any slight defect in the plane of rail surfaces would soon be corrected, as has been stated by Professor Johnson.

No doubt it is of paramount interest to secure the manufacture of rails without external or internal defects; this is admitted. There can be no doubt that a great error was committed some years ago in advocating the use of very mild steel.

When we can secure a steel that has a limit of elasticity of not less than from 50 000 to 55 000 pounds to the square inch, and which will undoubtedly entail a corresponding reduction of the modulus of elasticity, much benefit will result, as can at once be seen if any of the formulæ cited in this paper and discussion be received as approximately correct. With a bearing over the entire flat top of the rail head, it becomes of the utmost importance that all parts of the head be properly supported. Hence, is here found one of my objections to the Sandberg pattern, and it is the belief of the author that we should return to an approximation to the old pear shape in forming that portion joining the head with the web, and in the event that our loads increase within the next decade in anything like the proportion they have in the last, we may find it economy to adopt a form of rail having two webs, like unto the Strickland or Brunel rail.

Intimately connected with the subject of rail forms is that of the splice, and it is indeed impossible to consider the rail problem properly without reference to it; but as that matter is beyond the immediate scope of the paper under discussion, no further reference will be made to it other than to say that the author is of the opinion that the flange splice as generally designed presents about the most ugly appearance, mechanically considered, of all our railway appliances.

Objection has been raised to the form of rail head suggested, on the ground that it cannot be rolled and secure that compactness in the head that can be secured in the ordinary forms.

The opinion of our member, Mr. Hunt, who, by his experience of over thirty years in the manufacture of rails, can, I believe, be considered the superior of Mr. Sandberg as a manufacturer, and he can also be considered his peer as an inspector, is deserving of consideration in the matter of the practicability of rolling the form suggested.

The author is informed by Kennett Bayley, M. Inst. C. E., and Chief Engineer of the Great Southern and Western Railway of Ireland, that some seven years ago he changed the radius of his rails from 9 inches to 18 inches, and the result has been most gratifying in giving increased

service, and to his knowledge no English rail manufacturer has objected to the form.

The author, in his endeavor to compound the evil, has lately designed two patterns of rail, each having a top radius of 18 inches, and no manufacturer has objected to the guarantee of service that is applied to the usual design. After diligent inquiry, the author has failed to learn that any objection whatever has been made by manufacturers of the flat headed rails of the Northern Railway of France; hence the author concludes that the idea of want of compactness or sponginess in the heads of such rails is a myth, existing not, however, in the head of a flat topped rail.

During the time the author's paper has been under discussion, the final report of the Committee on the proper relation to each other of the sections of railway wheels and rails, has been made, and he may be pardoned in quoting from the preliminary and final report the following passages; the author calls especial attention to the words italicized by him :

From the preliminary report, page 42.	From the final report, page 4.
Your Committee are not clear that even if we consider the top bearing only, when no question of consequent rubbing friction comes in, it can be stated without many allowances, *that increase of bearing surface is in itself an advantage.* * * * *They are rather disposed to believe that it would be entirely disadvantageous.*	The prevailing sentiment, *which your Committee shares,* appears to be that the end sought in the suggestion of an entirely flat top between the rounded corners, viz.:—a wider bearing for the wheel tread, is a *desirable one,* but that it is and will be better secured in practice by using a slight curve for the top of the section instead of a straight line.

As between the preliminary and final report, an important advance in the right direction is made in the latter, and now only two more modifications are required to fully comply with the views of the author, viz:—that the broad surface of the rail-head be flat and that wheels be cylindrical.

In conclusion, the author desires to say that, knowing the persistency of evil, particularly when fortified by precedent, he fully expected to find himself the " under one " in this controversy. That so many agree with him in whole or in part is certainly gratifying. At the same time, his hearty thanks are due and given to those whose opinions are adverse to his premises, for the labor, ability and interest they have shown in this discussion.

If the paper and criticisms it has received will tend to arouse an interest in the matter treated, and cause the younger members of our profession, those who will soon be called to direct and design, to think of it—and by this expression I do not mean that they merely "think they think," but put absolute thought into the investigation—the author's desire will be in a great measure accomplished, and in the end, as he believes, his position vindicated.

ADDENDA.*

MODIFICATION No. 10, FEBRUARY, 1888.

3D DIVISION.—CONSTRUCTION AND INSPECTION.—COMPAGNIE DU CHEMIN DE FER DU NORD.—SPECIFICATIONS FOR FURNISHING STEEL RAILS.

Vignole Patterns... $\begin{cases} 43 \text{ K} \\ 94.8 \text{ lbs.} \end{cases} \begin{cases} 37 \text{ K} \\ 81.6 \text{ lbs.} \end{cases} \begin{cases} 35 \text{ K} \\ 77.2 \text{ lbs.} \end{cases} \begin{cases} 30 \text{ K} \\ 66.1 \text{ lbs.} \end{cases}$

ARTICLE I.

These specifications are intended to govern the delivery of steel rails.

ARTICLE II.

The rails will be of the American, called Vignole, pattern. They will conform exactly to a template which will be furnished the contractor. There must be no variation in the entire length of the rail from the above template, and particular care must be taken in cutting to length so as not to alter the end sections.

To allow for wear of rolls, and errors in setting of rolls, a deviation of 0.0005 meter (equals $\frac{1}{51}$ inch) will be allowed for the transverse dimensions of the rail, but in all cases the section must be symmetrical.

All rails not conforming exactly to template, within the above prescribed limits, will be rejected.

The standard weight per running meter will be determined by taking the average weight of one hundred of the rails first delivered, whose sections conform most nearly to the templates. A variation of 2 per cent. over or under the standard weight thus established will be allowed. Rails falling more than 2 per cent. below the standard weight will be rejected. Those being more than 2 per cent. above the standard weight will be accepted, but the contractor will not be allowed for any weight in excess of 2 per cent.

If the total weight furnished on a contract exceeds the estimated total standard weight by more than 1 per cent., the contractor will not be paid for this excess.

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* See Discussion by D. J. Whittemore, p. 169.

ARTICLE III.

The rails will have the lengths given in the following table, or such lengths as necessity may require.

Lengths of Rails for different Weights of Section.				REMARKS.
30 Kil.	35 K.	37 K.	43 K.	
Standard Lengths.				To be delivered in quantities not exceeding one-twentieth of the contract, as may be determined by the Chief Engineer of the company.
8 M. ·	6 M.	6 M.	12 M.	
7.96	5.96	5.96	11.91	
Short Lengths.				Lengths which will be allowed to facilitate the manufacture. The quantity of short length rails may vary at the option of the Railroad Company from one-twentieth to one-twenty-fifth part of the whole contract, a proportionate quantity of each length to be furnished.
7 M.	5 M.	5 M.	10 M.	
6 "	4 "	4 "	8 "	
5 "	—	—	6 "	

The Railroad Company reserves the right to order rails of a greater length than specified above.

There may be a variation of 0.002 meter ($\frac{5}{64}$ inch) in the length of a rail.

ARTICLE IV.

The rails will be marked, in plain raised letters and numbers, with the name of the mill, year and month of rolling. These marks will be cut into the finishing rolls.

Furthermore, near one end of each rail, the number of the charge and the quality of the steel in the ingot from which the rail was rolled will be marked with a cold chisel.

ARTICLE V.

The rails will be made from non-phosphorous metal by the Bessemer process; any other process of manufacture must first receive the sanction of the Chief Engineer of the Railroad Company. The operations of manufacture will be so conducted as to produce steel of the first quality, fine grain, compact, hard and tough, capable of being tempered, and similar in every respect to the sample which will be furnished to the Railroad Company by the contractor. The manufacture in quantity will not be commenced until the sample has been accepted by the Chief Engineer of the Railroad Company.

The steel will be run into ingots of rectangular section, not being less than 0.25 meter by 0.25 meter (9¾ by 9¾ inches), with rounded corners, or of circular section of at least 0.28 meter (11 inches) diameter. The size of these ingots will be so determined as to produce, when rolled, a bloom of 1 meter in length, for rails rolled in single lengths, and of 1.20 meter in length for rails rolled in several lengths.

The ingots will be examined with care, and those having blow-holes, impurities or other defects which rolling cannot eliminate, will be rejected. Small cavities and seams will be dressed with the greatest care, so as to avoid any possibility of overlapping of metal in rolling.

The Company's agent will have an ingot broken as often as he may deem necessary during the progress of manufacture. The fracture should be exempt from blow-holes. However, the number of ingots thus broken should not exceed one-five-hundredth of the total number.

The Company's agent will have the right to inspect the tests made on the runners taken at the time of pouring the ingots, from which the rails, subject to his control, are to be rolled. The rolling will be conducted in a manner to obtain rails of exact form, with smooth and uniform surfaces, and especially to avoid bending when the rails leave the finishing rolls. Those rails showing cold shuts, kinks, or flaws of any kind, will be rejected. Only small flaws which do not alter the shape of the section, or affect the strength of the rail, will be accepted, on condition that these flaws, after having been passed upon by the agent of the Company, are carefully dressed with a cold chisel and fine file, in the presence of the said agent.

All other patching up in a cold or warm state is forbidden. Rails not fulfilling the above requirements will be rejected.

ARTICLE VI.

The rails will be straightened on four sides with the greatest of care. The straightening will be done as much as possible when the rail leaves the finishing rolls in a hot state. If it becomes necessary to further continue the straightening operation, when the rails have cooled, it must be done by a gradual pressure, and without shock, so as to avoid creating any fissures in the rail. Dies of proper shape will be used to protect the flanges.

The rails, immediately upon leaving the finishing rolls, will have the crop ends cut off with a circular saw. The cutting to exact length may be done with a milling machine, or in any other way which will insure perfect work. The ends thus cut shall have perfectly plane surfaces, square to the axis of the rail. The heads at each end of the rail will be chamfered 0.0015 meter by 0.0015 meter ($\frac{1}{16}$ by $\frac{1}{16}$ inch) for a depth of 0.006 meter (¼ inch) from top of rail.

The burrs created in cutting will be carefully removed with a cold chisel and file. It is absolutely forbidden to hammer them off.

Reheating the ends of the rails and then cutting them with saw or shears is absolutely forbidden.

ARTICLE VII.

The rails of main line will be drilled and notched according to standard, or only drilled, as may be required. For rails of extraordinary length there will be special requirements.

The holes must be drilled in web, perfectly cylindrical, and of such diameters as directed. All burrs around the holes will be removed with the cold chisel and file. The positions of holes must not vary more than $\frac{1}{2}$ millimeter ($\frac{1}{51}$ inch) from those prescribed.

ARTICLE VIII.

The rails will be classed as they come from the mill, from day to day, into series. The authorized agents of the Company will select from each series a number, not exceeding 2 per cent., for the following tests.

Each of the rails will be placed over two points of support, 1 meter (3.28 feet) apart, and must carry, for five minutes, suspended at the middle between the two supports:

First.—Without permanent set after removing the load.

26 000 K. for the 43 Kil. type ⎫
20 000   "   " 37   "   ⎪   *Note.*—1 kilogram=2 205
18 500   "   " 35   "   ⎬   pounds.
17 000   "   " 30   "   ⎭

Second.—Permanent set must not exceed 25 millimeters (1 inch) at:

40 000 K. for the 43 Kil. type.
35 000   "   " 37   "
33 000   "   " 35   "
30 000   "   " 30   "

The rails may then be loaded to destruction.

Each of the two halves of a broken rail, placed on its side, between two supports spaced 1.1 meters (3.609 feet) apart, and fastened to a cast-iron base weighing 10 000 kilograms (11 tons), the latter resting on a block of masonry 1 meter (3.28 feet) high, and 3.3 meters (10.82 feet) square at the base, must endure, without rupturing, the impact of a hammer weighing 300 kilograms (661.5 pounds), striking the rail at the center between supports from the following heights:

3.00 meters height for the 43 Kil. type ⎫
2.50   "   "   37   "   ⎪   1 meter=3.28
2.40   "   "   35   "   ⎬   feet.
2.25   "   "   30   "   ⎭

After taking the impact successively from the following Heights	1 M.	1.5 M.	2 M.	2.25 M.	2.4 M.	2.5 M.	3 M.	
	Mm.	Mm.	Mm.	Mm.	Mm.	Mm.	Mm.	
The deflections should not	......	2	4	......	......	9	15	For 43 K. type.
vary more than 30 per	1	3	6	......	......	11	......	" 37 K. "
cent. from the figures here	1	3½	7½	......	12	......	......	" 35 K. "
given......................	2	5	11	16	......	......	......	" 30 K. "

The elasticity of the rail will be judged by the rebounding of the hammer.

If one of the rails thus tested breaks before a drop height of 2½ meters for the 37 K., 2.40 meters for the 35 K. and 2.25 meters for the 30 K. is reached, the tests will be repeated with other rails, and if more than one-tenth of the number of rails thus tested does not fulfill the requirements, the whole heat from which the rails were taken will be rejected.

The Company reserves the right to prescribe, and have made at the mill, any other tests which it may deem necessary, such as tension tests and the working of the steel into tools, in order to judge of the quality of the rails.

The test pieces for tension will be prepared cold, according to the instructions given by the Company's agent, and will be taken from the blooms or from the rails which were tested for impact. Cold chisels manufactured from the head and tempered under ordinary conditions must cut the surface of spiegel iron without dulling, becoming dented or doubling up. These various tests will be made independently, and the results will be written down and testified to by the agent of the Company and the agent of the contractor.

ARTICLE IX.

The agents of the Company will select, as fast as rolled, such rails as satisfy the requirements, and have them weighed and drilled, according to the conditions stipulated.

The contractor will furnish all necessary apparatus for testing, and all necessary help to facilitate the inspection of the steel. The accepted rails will be drilled at both ends, and the rails rejected will be marked at both ends, between the letters of the manufacturers' brand, with a special mark, plainly visible and indelible, so as to avoid the possibility of having rejected rails offered a second time.

ARTICLE X.

The manufacturer will warrant the rails during six years, commencing from the date of manufacture. Every rail which breaks during this time, or is damaged more than it ought to be by regular usage, will be replaced free of charge by the contractor. The exchange of rails damaged for new rails destined to replace them will take place at the point of delivery indicated in the contract.

ARTICLE XI.

The engineers of the Railroad Company, as well as their assistants, will have free access to the mills day and night, and be permitted to inspect all operations pertaining to the manufacture of the rails, and to make all necessary tests to satisfy themselves that the conditions of these specifications are being fulfilled.

ARTICLE XII.

The inspection by the engineer of the Railroad Company or by his agents at the mill, the tests and the preliminary acceptance of the rails manufactured, will not, in any case, diminish the responsibility of the contractor, which remains in full force until the expiration of his time of guarantee, as provided for in Article X.

ARTICLE XIII.

This contractor will be governed, except where these specifications conflict therewith, by the general stipulations relating to contractors of the Railroad Company, compiled by the Chief Engineer of Ponts et Chaussees, in charge of construction and inspection, on the 8th day of November, 1863, and approved the 10th day of the same month by a committee of the Directors of said Railroad Company.
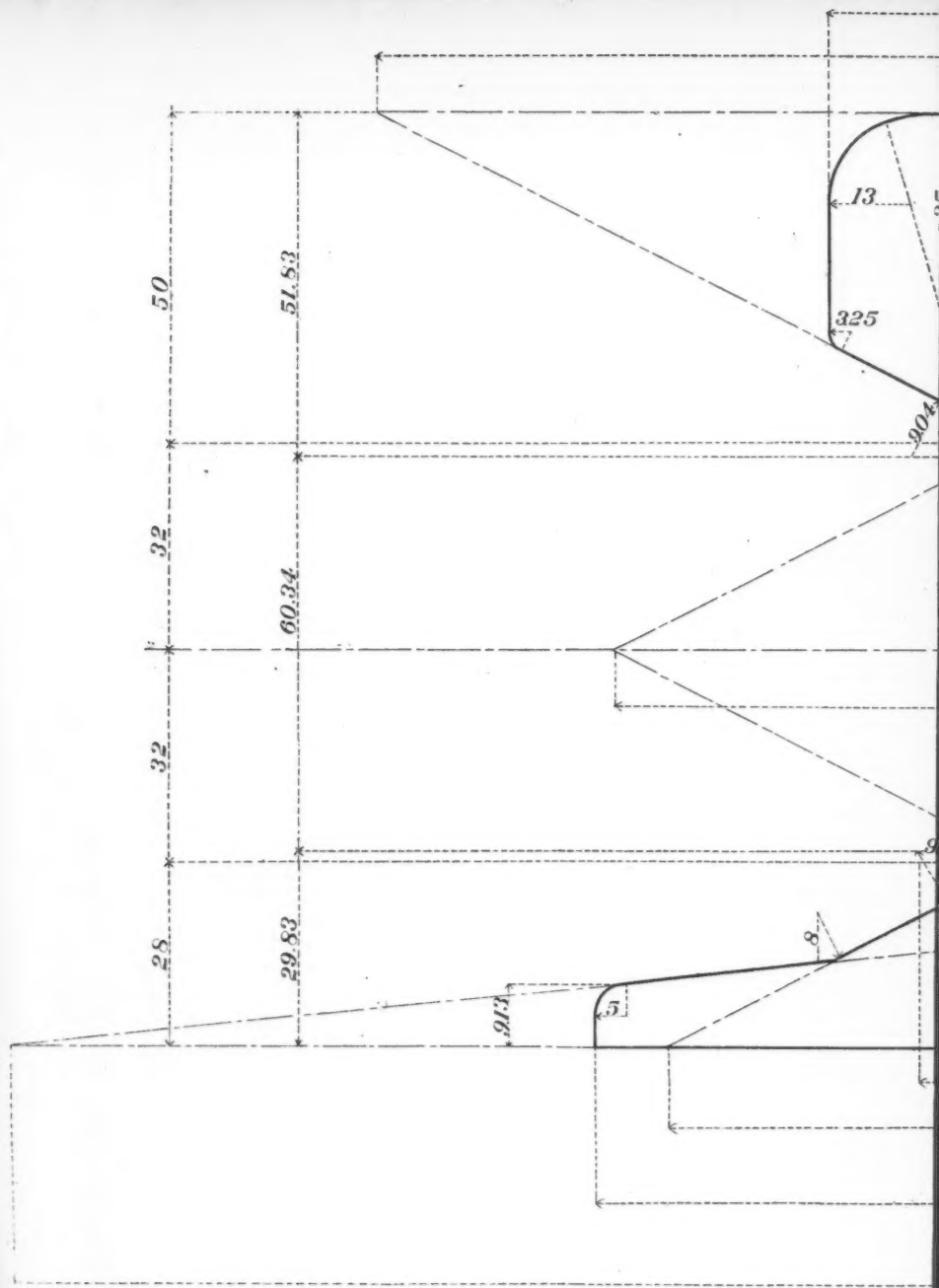
No deviation from these specifications or from the general stipulations will be allowed, except the same be authorized in writing by the Chief Engineer of the Railroad Company, which order the contractor must present at every requisition.
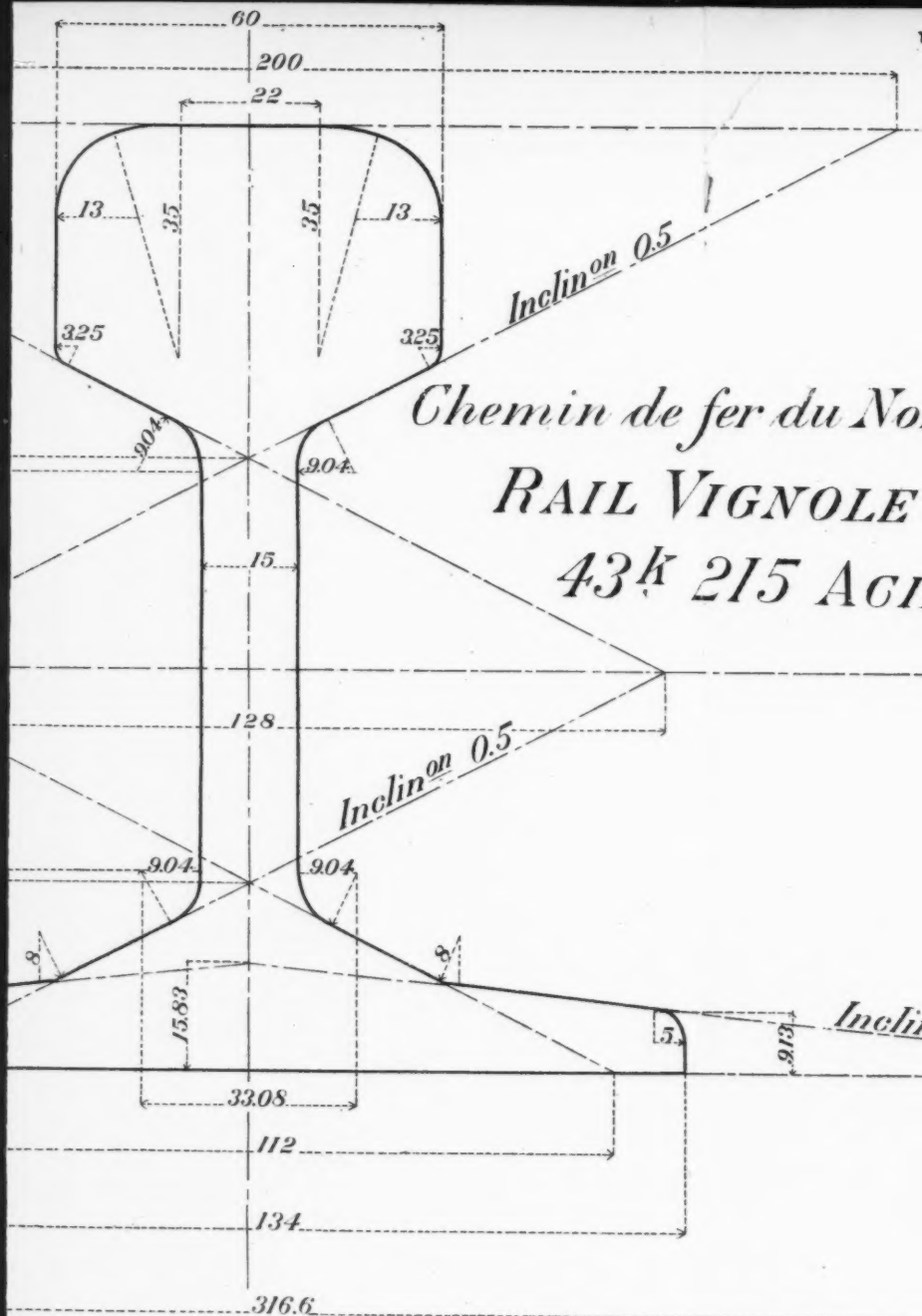
Compiled by the Chief Engineer in charge of Construction and Inspection, Paris, 1888.

Approved by the Operating Department.

Accepted by the undersigned contractor.

The section of rail is shown in Plate LXX.

Chemin de fer du No...
RAIL VIGNOLE
43ᵏ 215 ACI...

Nord 82

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